THERAPEUTICS OF THE CIRCULATION

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EIGHT LECTURES DELIVERED IN THE SPRING OF 1905
IN THE PHYSIOLOGICAL LABORATORY OF THE
UNIVERSITY OF LONDON

BY SIR LAUDER BRUNTON, BT.,
M.D., D.SC., LL.D. (EDIN.), LL.D. (ABERD.), F.R.C.P., F.R.S.
CONSULTING PHYSICIAN TO ST BARTHOLOMEW'S HOSPITAL

With the author's Compliments

PUBLISHED UNDER THE AUSPICES OF THE UNIVERSITY
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TO

HUGO KRONECKER

M.D., D.Sc. (Cant.), LL.D. (Aberd. and Glasg.)

ETC., ETC.

PROFESSOR OF PHYSIOLOGY IN BERNE AND DIRECTOR OF THE MAREY INSTITUTE IN PARIS

THE AUTHOR DEDICATES THIS BOOK

IN ACKNOWLEDGMENT OF THE GREAT SERVICES HE HAS RENDERED TO PHYSIOLOGY, AND ESPECIALLY THE PHYSIOLOGY OF THE CIRCULATION; IN MEMORY OF MANY PLEASANT HOURS SPENT TOGETHER WHEN WORKING IN LEIPZIG UNDER THE DIRECTION OF THEIR BELOVED MASTER CARL LUDWIG, IN 1869-70, AND IN TOKEN OF A FRIENDSHIP THAT HAS LASTED EVER SINCE.

PREFACE

THIS book consists of eight lectures which were delivered in January, February, and March 1905, in the Physiological Laboratory of the University of London, in accordance with the general purpose expressed by the University in the establishment of the Physiological Laboratory, viz., "to present the results of recent investigations by the investigators themselves, orally and with experimental demonstration in the lecture-room, and outside the lecture-room by monographs approved by the University."

By the kindness of Professor Waller and of his assistant, Mr Syme, the lectures were illustrated by experiments, which increased their value to the students. At the same time, the necessity of adapting the lectures to the experiments rather interfered with their orderly sequence, and in consequence of this they are not so sharply divided into the various sections on Physiology, Pathology, Pharmacology, and treatment, as they were at first intended to be. Semeiology is hardly touched upon, as it is so fully discussed in lectures on Medicine, and the other subjects were more than sufficient to fill a course of eight lectures.

Opinions may differ as to the proper selection of subjects for the lectures, and my selection may be disapproved of by some, who may consider that I have spent too much time over such subjects as "Self-massage of the Heart and Vessels," "The Conduction of Stimuli in the Heart," etc. My reason for doing so, is that I consider the subjects, on which I have dealt rather fully, to be of practical importance, and they are dealt with shortly, if at all, in ordinary text-books. I had also

made an experimental study of some of them myself, and in accordance with the general purposes of the University in establishing such lectures, I presented the results of my own investigations more fully than in a text-book. The lectures were not written out, but were delivered from short notes, so as to suit the experiments. They were taken down in shorthand by Mr M. A. Donaldson, and I have to thank him for the remarkable accuracy of his transcript. Although he supplied me with a type-written copy within a few days of the delivery of each lecture, yet the pressure of other engagements, and the difficulty of finding sufficient continuous time to obtain and arrange the illustrations and prepare the manuscript for press, has caused an interval of more than three years to elapse between the delivery of the lectures and their appearance in print. During this interval some new instruments for measuring the blood pressure in man have been brought out, and several of them have been described in an Appendix.

Owing to my ignorance of the rule that lectures delivered under the auspices of the University and printed with its sanction should be published by Mr Murray, these lectures were at first advertised to be published by Messrs Macmillan, who have published my other works, and the change was only made in accordance with the rule.

I have to thank both Mr Murray and Messrs Macmillan for their kindness and courtesy in regard to publication, and my thanks are especially due to Professor Waller for his interest and help, to Mr Syme for assistance in experiments, to Dr Oliver, M. Boulitte, Messrs Down, Mr Hawksley, and especially to M. Charles Verdin for many illustrations, and to Miss James for the very full index she has supplied.

Professor Kronecker has kindly supplied some most valuable notes of some of his own work and that of his scholars, which are printed in a special Appendix.

LAUDER BRUNTON.

August, 1908.

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ERRATA

Page 64, line 3 from bottom, *for* "palpitating" *read* "palpating."

Page 210, line 7 from bottom, *for* "anterior" *read* "interior."

Page 211, line 4, *for* "conductions" *read* "conductors."

THERAPEUTICS OF THE CIRCULATION

LECTURE I

Introduction—Harvey's Discovery—PHYSIOLOGY OF THE CIRCULATION: The Heart—Sleep of the Heart—The Arteries—Motor and Peristaltic Action of the Arteries—Capillaries and Veins—Action of Fasciæ—Accessory Muscles of Circulation—Flow of Lymph—Arterial Tension or Blood Pressure—Regulation of Blood Pressure—Heart and Blood Pressure—Arteries and Blood Pressure—Influence of the Muscular Area—Influence of the Splanchnic Area—Distension of Liver—Depressor Nerves—Independent Pulsation of Veins—Movements of the Heart—Views of Gaskell—Comparison between the Heart and a Medusa—Experiments of Romanes—Transmission of Stimuli in the Heart—Nervous and Muscular Conduction in the Heart—Experiments of Brunton and Cash—Conduction of Impulses both by Muscle and Nerve—Valves of the Heart.

THE subject of these Lectures is "The Therapeutics of the Circulation": the means by which we can put right anything that may have gone wrong with the circulation. If I were to hand my watch to any one of you, and tell you that it was not going properly, you would naturally hand it back to me and tell me to take it to a watchmaker; because you know nothing of the way in which watches are built, of the disorders to which they are liable, or the way in which to put them right. In the same way, before you can put anything right which has gone wrong with the circulation, you must know something about: (1) its normal working, or physiology; (2) of the disorders to which it is liable, or pathology; (3) of the means by which we can act upon it, or pharmacology; (4) of the indications by which we

recognise the particular disorder, or semeiology; and (5) the methods of applying our remedies to the disorders which we have already recognised, or therapeutics.

It is evident that, before we can deal with therapeutics satisfactorily, we must take up, to a certain extent, the other subjects upon which it depends, and, although you have studied them all to a certain extent already, I think it will be advisable to go shortly over them, more especially as I shall have to take them in definite relation to their practical use, instead of merely considering them as scientific subjects unconnected, possibly, with practical medicine. But the treatment of these must necessarily be very brief, because the subject-matter to be considered is very great.

Harvey's Discovery.—There is, perhaps, no discovery, either ancient or modern, which has had such a far-reaching influence on the health of human beings as the discovery by Harvey of the circulation. The truth of this discovery was at first denied, then its importance was belittled, then it was attributed to other men; but now its full importance is recognised, and the claims of Harvey to the discovery acknowledged. When we look at Harvey's work, it seems almost incredible that for so many thousands of years men should have overlooked the circulation. When we read Harvey's own account of his discovery, it seems one of such amazing simplicity that one is inclined to think that nobody could have helped making it. In his own words, it occurred to him "whether the blood might not go round, as it were, in a circle." That it did go round, Harvey showed by the blood issuing from the proximal end of a cut artery, and from the swelling of the veins when obstruction was put between the periphery and the centre.

One of the great reasons why the blood had been supposed not to go round, but to flow backwards and forwards, probably was that the ancients looked upon the arteries as conveying air alone instead of blood, or else conveying a mixture of air and blood. They seem to have come to this conclusion from the fact that the arteries were generally found empty in animals that had been killed for sacrifice, and the reason of this emptiness I shall discuss later on (p. 5).

Physiology of the Circulation

The Heart.—The great motor power which keeps the circulation moving in a circle is the heart, although its action is supplemented by other mechanisms in the vessels and tissues. We are sometimes accustomed to speak of this "unresting" organ, but this is a total mistake. The heart rests in an adult more than thirteen hours out of the twenty-four; the time of rest being the diastole, and the time of work being the systole.

Sleep of the Heart.—We may say, then, that the heart practically sleeps more than the brain or the body; but the great distinction between the sleep of the heart and that of the brain, is that the sleep is so short at a time. There are very few healthy men who could not walk a thousand miles in six weeks, walking a little over eight hours a day at an easy pace, and resting for the remainder of the period; but there are not many men who could emulate the feat of Captain Barclay, of walking a thousand miles in a thousand hours, because the frequent interruptions to their sleep would exhaust them completely; and still fewer are there who could walk a thousand miles in a thousand half-hours, as has been done by various men since Captain Barclay's time. In such trials of endurance a man usually walks two miles at a time, the first mile at the end of one hour or half-hour, and the second at the beginning of the next hour or half-hour. Supposing he walks at the rate of four miles an hour, *i.e.* a mile in a quarter of an hour, he gets an hour and a half for sleep between every walk when doing a thousand miles in a thousand hours, but only gets one-third as much sleep, viz., half an hour, between his walks when doing this distance in a thousand half-hours. An attempt to do a thousand miles in a thousand quarter-hours is obviously impossible;—if a man walked at the rate of four miles an hour, there would be no time for rest at all, the whole time being required for walking. A little time might, no doubt, be gained by increasing the pace; but this would of itself involve greater exertion, and the time thus gained would be quite insufficient for recuperation.

In the same way, when the heart is forced to beat more quickly than normal, it is more and more quickly exhausted the

higher the pulse-rate rises, for nearly the whole time for the extra work is taken from the diastolic pauses of sleep of the heart, even though the systole may be slightly shortened. Hence the importance of slowing the pulse-rate by cold, by drugs, or by other measures, when it tends to become too rapid.

Perhaps it may be as well here that I should note that the heart, at certain periods, is resistant to external stimuli. When Captain Barclay was taking his sleep between his walks, he would be more and more ready to respond to a chance call the nearer the time came for him to begin again; but while actually engaged in his walk, he would be too much intent upon his work to heed a call from anyone. In the same way, we find that during the period that the heart is contracting it will not respond to a stimulus which, if applied immediately after its action is over, would cause it to contract again. This period, which we have to consider later on, is called the refractory period.

The Arteries.—Now, if the heart is only acting for eleven hours out of the twenty-four, and is entirely cut off from the aorta by the closed aortic valves, what force is carrying on the circulation during the whole of the other thirteen? This force is the elastic recoil of the arteries, which have been stretched by the blood forced into them during the ventricular systole, but which, if healthy, again contract during the diastole. The vessels thus act as a storage of energy, just as a watch-spring does when wound up every night, or as the water driven by a force-pump into a high tank from which a house or town can be supplied, or the elastic bag in a spray-producer.

The arteries have really three functions. They not only act as (1) storers of force, but as (2) regulators, and as (3) motors. Their power of regulating the supply of blood to different parts of the body was known to Harvey, who said:—"It is manifest that the blood in its course does not everywhere pass with the same celerity, neither with the same force in all places, and at all times. . . . In fear, and under a sense of infamy and of shame, the face is pale; but the ears burn, as if for the evil they heard or were to hear." As my old teacher, Professor Ludwig, used to put it, "There is not nearly sufficient blood in the body to fill all the vessels at once, and the vaso-motor system, which

regulates the size of the arteries, is like the turncock in a large town who turns off the water supply to one district at the same time that he turns it on to another;" just as in Harvey's observation, the vessels became contracted in the face at the same time as they became dilated in the ear.

Motor and Peristaltic Action of Arteries.—The motor action of the arteries has received less attention; but it is, I think, very important, and is, I believe, the cause of the emptiness of the arteries after death, which so long prevented Harvey's discovery from being made. When working under Professor Ludwig in 1869, he directed my attention to the contractile power of the small arteries apart from any nerve centre, and while watching their movements I have sometimes seen a regular peristaltic action take place, by which the blood was driven forward in the arteriole, just as fæcal matter would be driven forward in the intestine.[1] Such action may empty the arterial system after death (p. 2).

Capillaries and Veins.—From the arteries the blood passes into the capillaries, and some of its liquid parts leak through their walls to supply the needs of the tissues, while the remainder, along with the blood corpuscles, passes into the veins. It is the heart which is the motor power for the blood in the veins also; but it would barely be sufficient to carry on the circulation and bring the blood back to the heart again, were it not for various helping agencies. One of these is the suction exerted by the movements of the respiration, and another is the suction exerted by the heart itself during the ventricular contraction, which drives the blood out of the thorax, through the aorta, and sucks it in through the veins.

One very important adjunct to the heart in keeping up the venous circulation, is intermittent pressure upon the veins from without, aided by numerous valves in the veins themselves; so that while each pressure pushes the blood a little onwards, its return is prevented. External pressure is produced by muscular action. Each contraction of a muscle squeezes the blood and also the lymph out into the veins and lymphatics, both of which

[1] Lauder Brunton, *Sitz. ber. d. k. säch. Gesellsch. d. Wiss.*, 1869, s. 285; and, *Ludwig's Arbeiten*, 1869, s. 101.

have very numerous valves at short distances apart. But every beat of the arteries, as a rule, tends also to help on the venous blood, for the arteries and veins usually have a common sheath of unyielding fibrous tissue, and each time that the artery is distended during a ventricular systole it tends to push a corresponding amount of blood onwards through its accompanying vein. (Fig. I.)

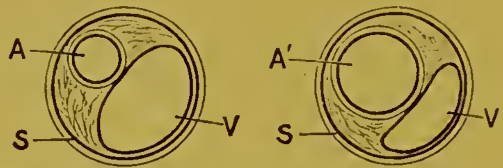


FIG. 1.—Diagram to show the effect of the arterial pulse in aiding the onward flow of venous blood and lymph, by a process of what may be called self-massage. A is an artery during diastole. V is a vein filled with blood. S is the fibrous sheath which encloses the artery, the vein, and the lymph space around them. A' is the artery distended with blood by the ventricular systole. As the sheath S' is unyielding, the distension of the artery forces the blood out of the vein and the lymph out of the lymph space, and as the backward flow of both is prevented by the valves of the veins and lymphatics, the circulation is increased in both.

Action of Fasciæ.—In addition to these mechanisms, however, we have the pressure upon the veins by the fasciæ of the limbs, and Braune has shown that when the veins are stretched, their capacity is increased, and they suck blood into them. The veins of the upper limbs are most stretched when the fists are clenched, the hands bent somewhat down, and the arms extended and pushed rather backwards—the very attitude, indeed, that is assumed by a man who has been sitting for a length of time at a writing-table and feels himself cramped in consequence. The veins become relaxed when the leg is bent and turned slightly inwards, whilst the veins become stretched when the foot is turned outwards and the leg extended and pushed somewhat backward. The first of these positions is nearly that assumed by one leg when we advance it for the purpose of walking, and the second when we move the body and other leg forward (Braune-Ludwig's *Festgabe*, 1874).

Accessory Muscles of Circulation.—The late Professor Sharpey used to insist a good deal upon the functions of the rotators of the leg, and he pointed out that in books on anatomy the trunk is looked upon as a fixed point, and the rotation is discussed in terms of this; so that we say that the function of the tensor vaginæ femoris is to rotate the leg inwards upon the body, and

that of the gluteus maximus to rotate it outwards. In reality, he said, it is the leg which is the fixed point in walking; and the function of these muscles is to rotate the body on the leg, the tensor vaginæ femoris rotating, not the leg inwards, but the body outwards, so as to bring the centre of gravity over the foot. But in view of Braune's observations these muscles acquire a new value. We speak very frequently of accessory muscles of respiration, but I have not seen anywhere the tensor vaginæ femoris and the gluteus maximus spoken of as accessory muscles of circulation, yet both they and the muscles of the calf and thigh may well deserve such an appellation.

Flow of Lymph.—This description of the circulation, however,

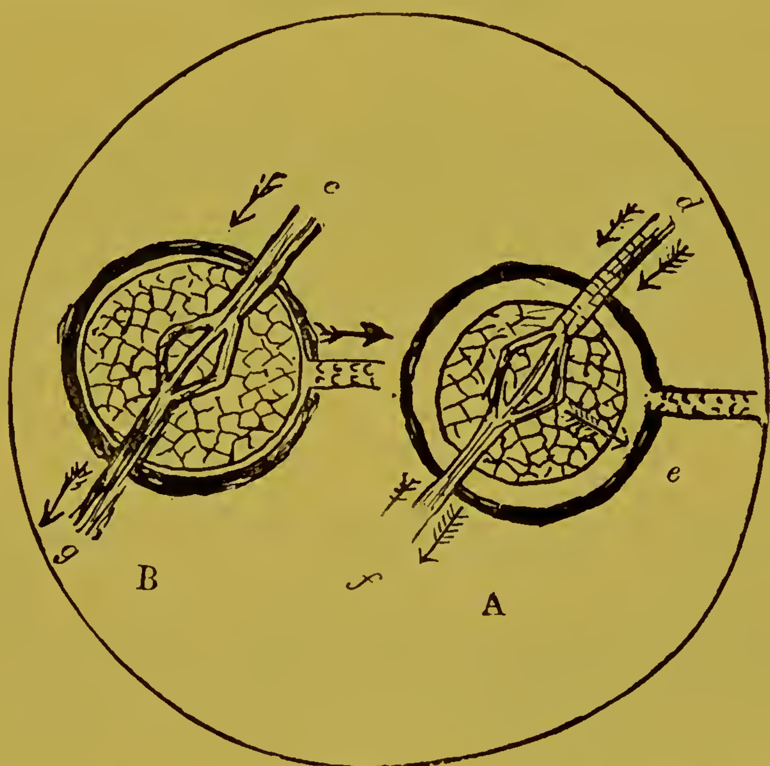


FIG. 2.—Diagram of transverse section of voluntary muscle to show the pumping action exerted on the muscle-juice and waste products during action. The blood-vessels cross diagonally. To the left (B) the muscle is contracted and presses the two layers of the fascia together, so as to drive the muscle-juice out into the lymphatics. To the right (A) the muscle is relaxed, and tends to draw the layers of fascia apart and suck the juice out of the muscle into the lymph space. *c*, Artery. *d*, Artery. *e*, Lymphatics. *f*, Vein. *g*, Vein. The double arrows in A are intended to indicate the increased blood-flow through the muscle, and the single arrow within the muscle to indicate the passage of fluid from the muscle into the lymph space between it and the surrounding fascia.

would be insufficient without a consideration of how the lymph flows, for the circulation of the lymph is quite as necessary as

that of the blood itself. Here also the muscles form one of the most efficient sources of motor power. At each relaxation of a

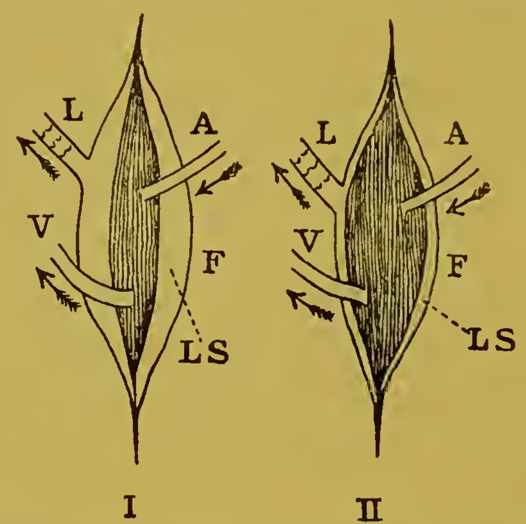


FIG. 3.—Diagram of longitudinal sections of muscles, I. in relaxation and II. in contraction. F is the fibrous fascia or sheath of the muscle. L S a lymph space between the muscle and the outer layer of fascia. L is a lymphatic vessel with numerous valves, by which the lymph containing waste products is removed. A is an artery by which fresh blood is brought to the muscle; and V is a vein by which blood is removed from it. Each time the muscle contracts, as in II., it lessens the size of the lymph space and drives the lymph onward through the lymphatics. Each time it relaxes it tends to create a vacuum within the fascia, and thus lymph is sucked out of the muscle into the lymph space, while fresh arterial blood rushes into the muscle.

muscle it tends to cause a vacuum within its surrounding fascia, into which the lymph flows from the muscular structure. At

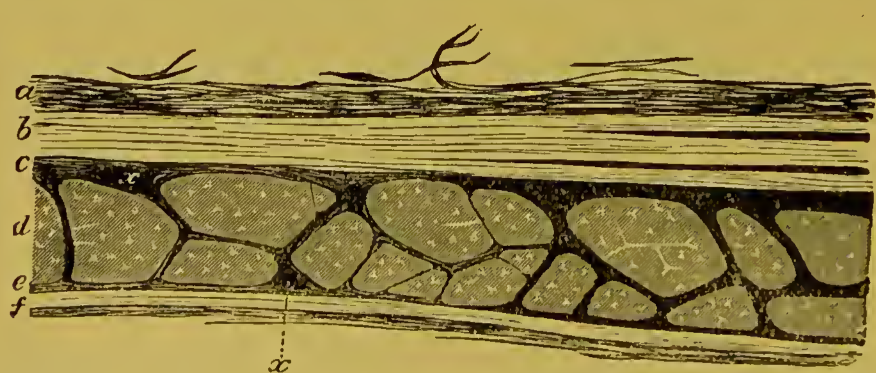


FIG. 4.—Injected lymph spaces from the fascia lata of the dog, after Ludwig and Schweigger-Seidel, *Lymphgefässe der Fascien und Sehnen*. The injected spaces are black in the figure, and the muscular bundles are seen in the cross-section embedded in lymph.

each contraction the muscle presses this lymph out, and these alternating muscular movements really act as a subsidiary heart, and do away with the necessity of having in mammals the lymph hearts which are seen in the frog. (Figs. 2, 3, and 4.)

In the pleura and the diaphragm the movements of respiration have a similar pumping action on the pleural and peritoneal fluids. (Figs. 5 and 6.)

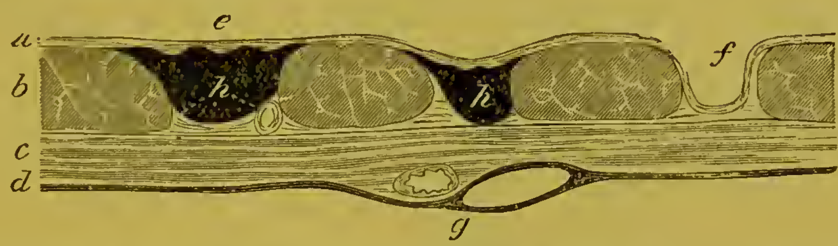


FIG. 5.—Section of the central tendon of the diaphragm in the rabbit. *a*, Peritoneum; *b*, tendinous fibres in cross-section; *c*, circular fibres; *d*, the pleura; *e*, peritoneum stretched over a full lymph space; *f*, peritoneum lying in an empty lymph space; *g*, blood-vessels. (After Ludwig and Schweigger-Seidel.)

It may seem that I am spending too much time upon points in the circulation which you all know, but I shall have to return

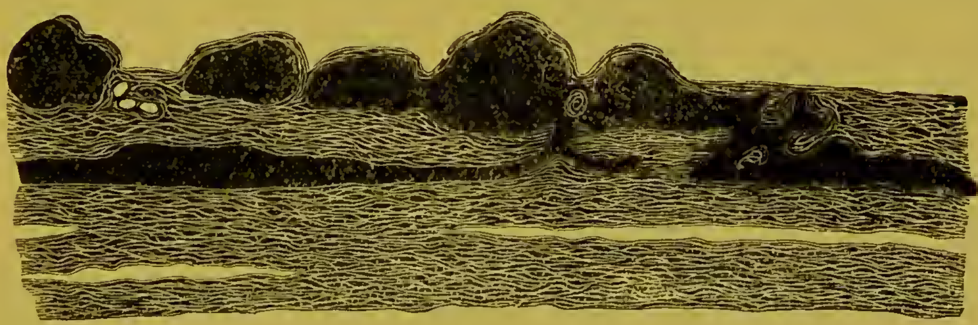


FIG. 6.—Section of the pleura. The lymph spaces appear black in the figure. (After Ludwig and Dybkowsky.)

to them again in discussing Treatment, and unless I had put them before you now in the way I have done, you might not be so readily able to perceive the reason for the therapeutic measures which I shall afterwards have to mention.

FIG. 7.—Diagram of the circulation. *a*, the heart completely shut off by the valves during diastole from *b*, the arteries; *c*, the capillaries; *d*, the veins; *e*, mercurial manometer; *f*, a float; *g*, a recording cylinder.

Arterial Tension or Blood Pressure. — During the long sleep of the heart — thirteen hours out of every twenty-four —the circulation is maintained by the contractile force of the arteries, which presses the blood out through the only opening which, in health, is available, namely, through the capillaries.

This contractile force is, of course, to a great extent, due to elasticity, especially in the larger arteries, although in the arterioles it is probably chiefly due to contractility. The force with which the blood would be pressed out if a vessel were

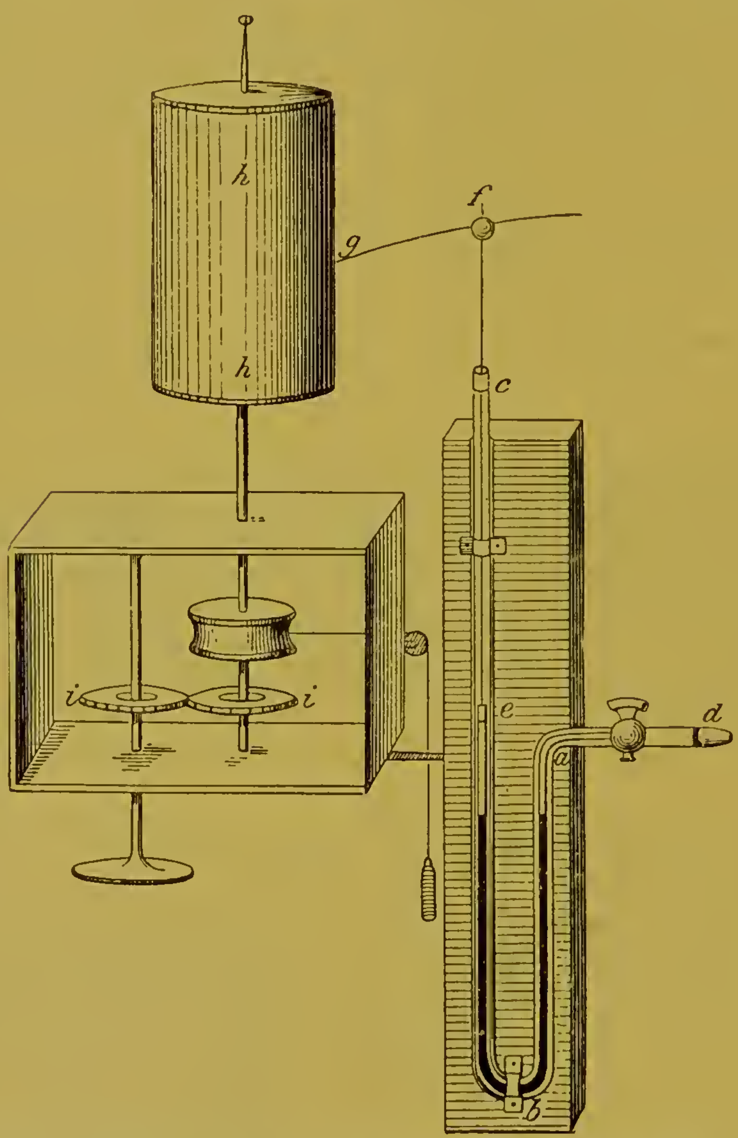


FIG. 8.—Ludwig's kymograph. *a b c* is a simple mercurial manometer such as was used by Poiseuille. *c b* and *g* are the float, and *h* the recording cylinder, and *i* the clockwork added by Ludwig.

opened or a cannula put into it, is known as the blood pressure, and this is usually estimated by connecting an artery with a mercurial manometer and seeing the height of mercury required to counterbalance the pressure in the vessels. This was first

estimated by a clergyman, the Reverend Stephen Hales,[1] who, after cutting an artery in an animal, and after connecting a glass tube with the artery, noted the height to which the blood rose in the tube. Poiseuille[2] improved upon this plan by connecting the artery with a mercurial manometer, and an immense advance was made by Ludwig,[3] who registered the movements of a manometer on a revolving cylinder. (Fig. 8.) Although

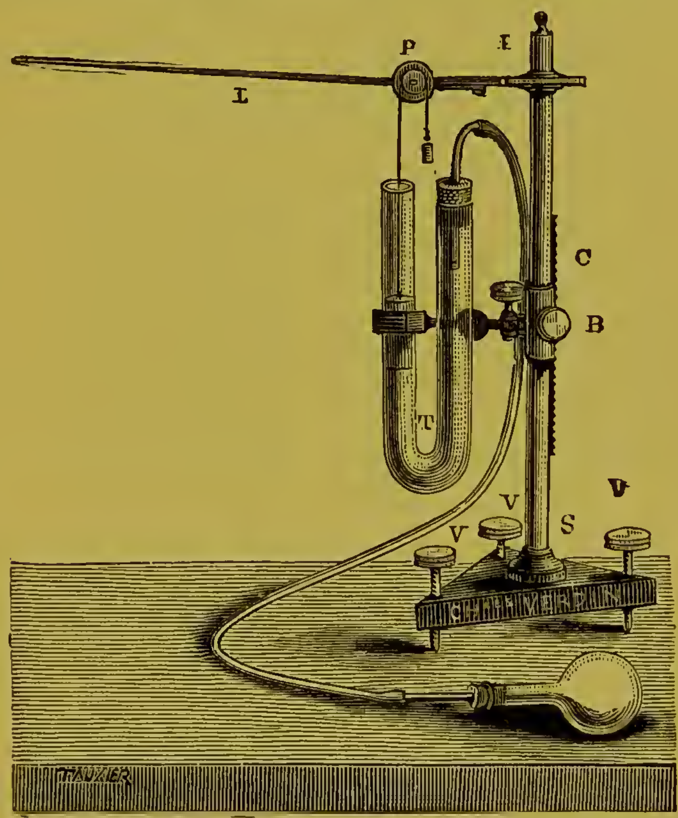


FIG. 9.—Lelaunié's manometer. It consists of (T) a bent tube containing mercury. The open arm bears a float, the movements of which are transmitted by a pulley (P) to the lever (L), which amplifies and records them. By means of a pinion (B) working on a rack (C), the apparatus can be moved up and down on a stand (S), which is rendered vertical by three screws (V V V). The open end of the tube can be connected with a caoutchouc bag, as in the figure. It was originally designed to record the rectal temperature in a dog during tetanization, but it could be used for other purposes. Burdon-Sanderson's kymograph was similar to this, but the two limbs of the U tube were of unequal width, and the lever was longer.

he did this in 1847, yet in 1865, when I first began to work at the action of drugs on the blood pressure, there was, I believe,

[1] Hales, *Statistical Essays*, London, 1733, vol. ii., p. 1.

[2] Poiseuille, *Magendie's Journ. de la physiol.*, viii., p. 272, 1828; ix., 1829, p. 343.

[3] Ludwig, *Arch. f. Anat. u. Physiol.*, 1847, s. 242, Taf. x.-xiv.

not a single recording manometer in this country,[1] and it was only at this time that one was first made by Sir John Burdon-Sanderson,[2] and used by him in his research upon the relationship of respiration to circulation. It was just a little before this that Marey[3] invented his sphygmograph, by which much interesting information has been gained regarding the circulation in man. (Fig. 120.).

Regulation of Blood Pressure.—The blood pressure, one may roughly say, depends upon the difference between the amount

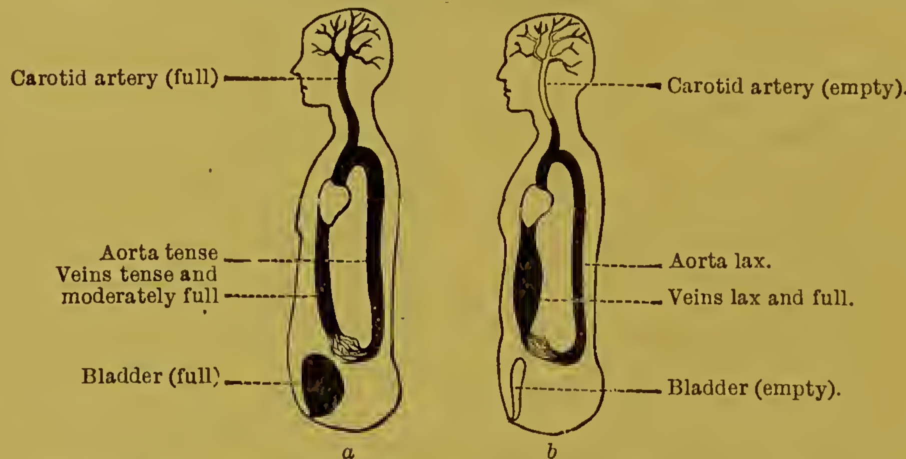


FIG. 10.—Diagram to show the causation of syncope. In *a* the carotid artery is full, the aorta full, the veins contracted, and the bladder is full. In *b* the carotid is empty, so that the brain is insufficiently supplied with blood, and syncope ensues. The tension in the aorta is low, as indicated by its smaller size, the veins are full, and the bladder is empty.

pumped by the heart into one end of the arterial system and the amount leaving by the capillaries in any given time. It is obvious that unless some means existed by which these two factors could be brought into proper relationship, much mischief might be done. If the heart were to continue pumping in blood whilst the arterioles were tightly contracted, the heart would either become strained or a vessel would burst, as it does in apoplexy. On the other hand, if the arterioles were dilated and the heart did not beat more actively in order to

[1] Lauder Brunton, "On Digitalis," *Collected Papers on Circulation and Respiration.* First Series, pp. 52 and 104. London : Macmillan & Co.

[2] Burdon-Sanderson, *Roy. Soc. Proc.*, xv., 1857, p. 391 ; *Phil. Trans.*, clvii., 1867, p. 391.

[3] Marey, *Mem. Soc. Biol.*, 1859, p. 281 ; *Compt. rend.*, 1880, l., p. 634.

supply a larger amount of blood, the arteries would very likely become empty and the pressure in them so low that the circulation through the various organs would be insufficient to maintain their functional activity, and the brain, being especially sensitive, syncope would result. (Fig. 10.)

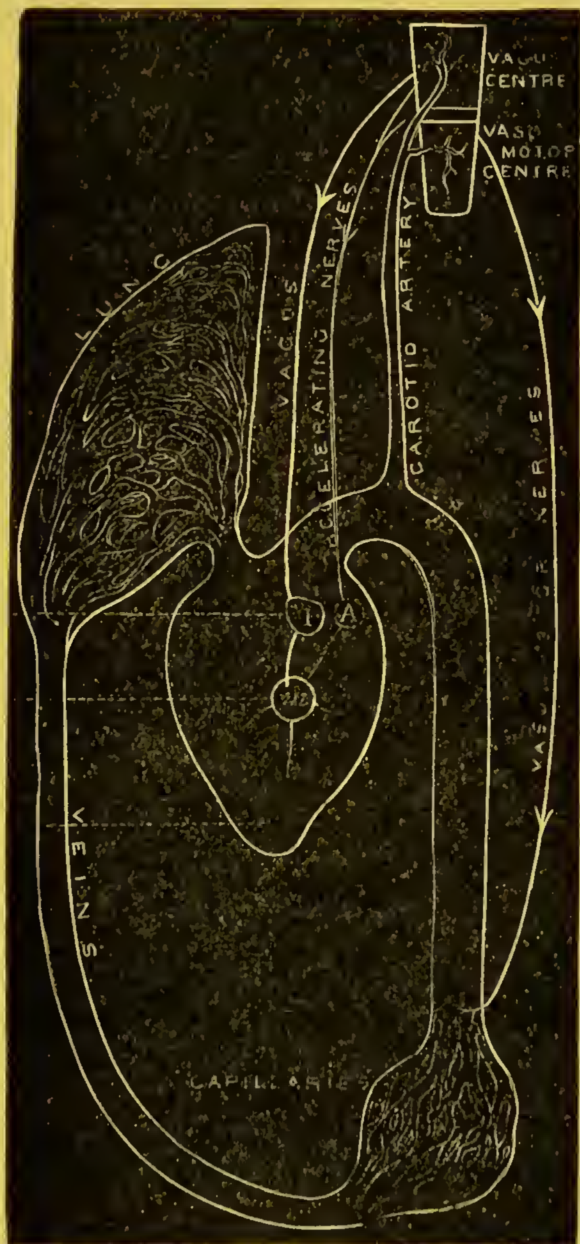


FIG. 11.—Diagram to show the nervous apparatus by which the action of the heart and vessels is co-ordinated so as to maintain an equal blood pressure. A is the accelerator apparatus.

Heart and Blood Pressure.—Co-ordination is maintained by means of the nervous system, the chief centre of which is in the

medulla oblongata, where the most important part of the vaso-motor centre is located, and where also the vagus roots are situated. By irritation (*a*) of the vagus roots, or (*b*) of their trunks, or (*c*) of their ends in the heart, the movements of the heart become slower and often weaker (Fig. 133), although the

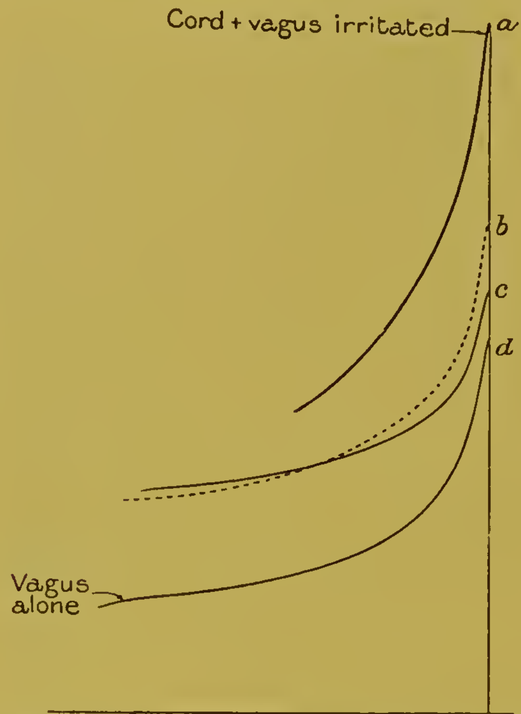


FIG. 12.—After Ludwig. *Ludwig's Arbeiten*, 187, p. 106.—Shows the rapidity with which the blood flows through the vessels of the muscles. When the heart is stopped by irritating the vagus the arterial pressure falls continuously, as the blood flows out of the arteries into the veins through the vessels of the intestines, muscle, and brain. The higher the pressure the more quickly will the blood flow through them, and, other things being equal, the quicker will the pressure fall.

The curves are taken from the arterial pressure in a middle-sized dog whose spinal cord had been divided high up in the neck. *a*, *b*, and *c* show the rapidity of fall of blood pressure at various heights during simultaneous stimulation of the vaso-motor nerves in the spinal cord and stoppage of the heart by stimulation of the vagus. In *d* the vagus alone was stimulated.

If the assumption were correct that all the arterioles in the body were contracted by stimulation of the vaso-motor nerves in the cord, the blood pressure should hardly fall at all during stoppage of the heart, when the vaso-motor centre is stimulated at the same time. But the curves *a*, *b*, and *c*, and especially *a*, show that it falls with such rapidity that it must be assumed that the blood flows through the vessels of the muscles which are not under the same control of the vaso-motor centres as those of the intestine.

slowing and weakness may occur more or less independently of each other (*cf.* pp. 98, 99, and 101). Any excessive tension in the vessels, involving as it does the blood supply of the medulla, acts as an irritant to the vagus centre, puts the vagus nerve into action, slows the heart,[1] and thus prevents the tension

[1] This has been shown in a brain kept alive by artificial circulation and separated from the rest of the body, except that the vagi remained intact,

from rising too high. (Fig. 11.) On the other hand, diminished pressure in the arterial system lessens the normal stimulation of the vagus centre, and in consequence the vagus nerves act less powerfully on the heart, its beats become quicker, and the pressure rises.

Arteries and Blood Pressure.—On the other hand, the vaso-motor centre when in action causes the arterioles, especially of the intestines and of the skin, to contract, so that the channels by which the blood can pour from the arteries into the veins are diminished in size, and the pressure, consequently, tends to rise.

Influence of the Muscular Area.—There are, however, a number of arteries which are only slightly influenced by the vaso-motor centre, for, when this centre is irritated so as to contract all the vessels of the skin and intestines to the utmost, blood may still pour through those vessels which supply the muscles so rapidly that the effect of the vaso-motor centre hardly appears to be felt at all. (Fig. 12.) Nevertheless, Waller noticed that sometimes by stimulating this centre the tension may rise so high as to prevent the heart from beating. These different results depend, of course, upon the different animals experimented upon and the different conditions under which the experiments are made.

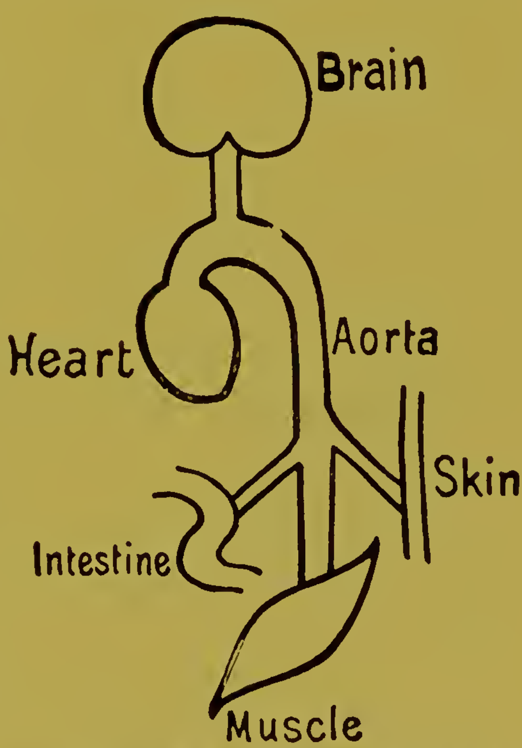


FIG. 13.—Diagram showing the four great areas for the distribution of blood in the body, viz., the muscles, the intestine, the skin, and the brain.

Influence of the Splanchnic Area.—The four largest vascular districts in the body are those of (1) the splanchnic area, (2) the muscles, (3) the brain, and (4) the skin. (Fig. 13.) It is the splanchnic area which is

so that the brain could act on the heart.—François Franck, *Trav. du laboratoire de Marey*, 1877, vol. iii., p. 276.

more especially under the influence of the vaso-motor centre. Any disturbance of the circulation in this area greatly modifies the blood pressure, and section of the splanchnic nerves will reduce it enormously. The splanchnic area, therefore, serves to a great extent as a regulator of blood pressure, and when the portal vein is tied, the whole of the blood in the body, or at least a large part of it, will collect in the vessels of the intestines and in the liver; so that, to use Ludwig's words, "an animal may be bled into its own veins."

In 1868 Ludwig[1] and one of his pupils made some experiments upon the secretion of bile by an excised liver, through

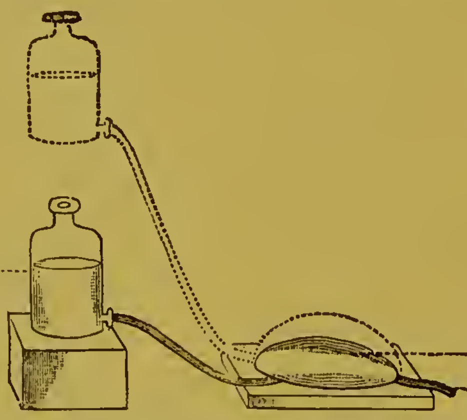


FIG. 14.—Diagram to show the effect of artificial circulation of blood through the liver, under different pressures. The continuous lines indicate the size of the liver, and the arrangement of the apparatus during circulation, under a low pressure. The dotted lines indicate the increased size of the liver, and the arrangement of the apparatus, under a high pressure.

which a stream of blood was passed artificially; and on making experiments myself a year or two later,[2] I was very much struck by the enormous distensibility of the liver. One is misled in regard to this property by the hard, firm appearance of the liver after death; but during life the liver is more like a sponge, and reacts just like a sponge to the slightest difference in blood pressure, swelling up as the pressure increases, and diminishing as the pressure falls. (Fig. 14.)

Distention of Liver.—In the healthy body we do not notice

[1] Ludwig and Schmulewitsch, *Ludwig's Arbeiten*, 3ter Jahrg., 1868, p. 114.

[2] Lauder Brunton, *Burdon-Sanderson's Handbook for the Physiological Laboratory*, 1873, p. 505 *et seq.*; and, Lettsomian Lectures, 1885, in *Disorders of Digestion*, p. 25.

great changes in the liver, because the pressure in the portal system undergoes but very slight change. However, when there is backward pressure from the heart, in consequence of incompetency of the tricuspid valves, the liver sometimes becomes enormously large, reaching down to the umbilicus or even to the iliac fossa.

Depressor Nerves.—As I have already mentioned, when the tension is too great in the heart and aorta, it acts as a stimulus to nerves, starting from the heart and aorta, and causing reflex dilatation of the abdominal vessels; so that the tension in the aorta is thus relieved. These nerves may either run as a separate nerve, known as the depressor nerve,[1] or may be partly incorporated with the vagus trunk.

Independent Pulsation of Veins.—All through the veins the circulation is steady and even; but when we come to the vena cava and pulmonary veins, we find that these vessels may have a pulsatile contraction of their own, like that of the venous sinus in the frog. This action of the veins had apparently been lost sight of until Fayrer and I rediscovered it,[2] and we could not then find any mention of it in any of the ordinary text-books on physiology.[3] It was, however, well known to Haller,[4] and also to Senac,[5] a century and a half ago, and we have since found it had been noticed by Colin[6] a year or two before our observation. This contraction is not always present, and so it can hardly be regarded as a constant part of the cardiac pulsation.

Movements of the Heart.—Views of Gaskell.—In considering the motion of the heart, we begin, then, with the auricle, which contracts and drives the blood into the empty ventricle. The

[1] Ludwig and Cyon, *Ludwig's Arbeiten*, vom Jahre 1866, p. 128.

[2] Brunton and Fayrer, *Proc. Roy. Soc.*, 1874, vol. xxii., p. 125; and, *Proc. Roy. Soc.*, 1876, vol. xxv., p. 72.

[3] According to Rollett (*Hermann's Handbuch der Physiologie*, vol. iv., p. 152), it was known to Meibomius in 1668 and to Johannes Müller in 1835.

[4] Haller, *Elementa Physiologica*, 1757, tom. i., pp. 410 and 399; and, *Memoires sur la Nature Sensible et Irritable des Parties du Corps Animal*, 1756, tom. iv., p. 4.

[5] Senac, *Traite de la Structure du Cœur, etc.*, second edition, Paris, 1783, tom. ii., pp. 37 and 38.

[6] Colin, *Compt. rend.*, 1862, tom. 55, p. 495.

ventricle in turn drives the blood onwards into its corresponding artery. Formerly, the rhythmical action, both of auricles and ventricles, and the co-ordination of their action, were attributed entirely to nervous influence; but the observations of several writers, and particularly of Gaskell in this country, and of Engelmann in Germany, have led to the adoption of the view that both the rhythm and the co-ordination are characteristics of the muscle, and that the nerves of the heart have little or nothing to do either with its independent pulsation or with the regular sequence in which the action of the auricle follows that of the ventricle.

Heart of the Frog.—The heart of the frog being simpler in structure than the mammalian heart, and more easily studied, has

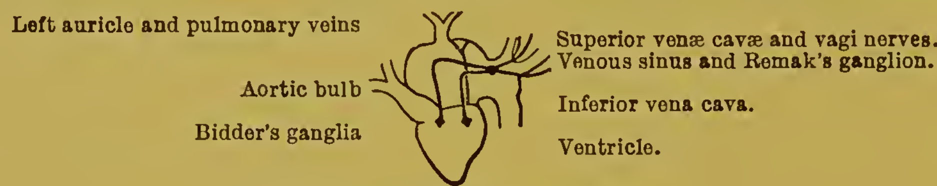


FIG. 15.—Diagram of the frog's heart.

been used to a great extent for the purpose of discovering the causation of the cardiac movements. It consists of the venous

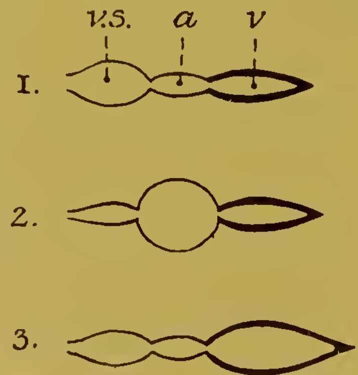


FIG. 16.—Diagram to show the successive contraction of the cavities in the frog's heart. *v.s.* is the venous sinus, *a* the auricle, and *v* the ventricle. In 1 the ventricle has just contracted and is empty. The venous sinus is full and just ready to contract. In 2 the venous sinus has contracted and filled the auricle, while the ventricle is still empty. In 3 the auricle has contracted and filled the ventricle, which is just ready to contract. The venous sinus is filling, and will shortly be ready to contract again, as in 1.

sinus, two auricles, one ventricle, and the aortic bulb. The vagi nerves pass to the junction of the venous sinus and auricle, and here form a plexus or ganglion known as Remak's. From this

a *b* *c*

FIGS. 17 AND 18.—AUTHOR'S DIAGRAMS TO ILLUSTRATE THE EXPERIMENTS OF STANNIUS.

FIG. 17.—*a*, diagram of frog's heart ligatured at the junction of the venous sinus with the auricles. The venæ cavæ and sinus are represented with a crenated outline resembling the tracing which their beats might give if recorded on a revolving cylinder. The auricle and ventricle being motionless would only trace a straight line if connected with a recording apparatus. Their outline is therefore represented by a straight line. *b*, diagram of a frog's heart in which sections have been made at the junction of the sinus with the auricles, and at the auriculo-ventricular groove. The sinus and ventricles pulsate, whilst the auricles remain motionless. The beats of the ventricle should have been represented as slower than those of the auricle, as in *f*, Fig. 18. *c*, the same as *b*, but with the parts of the heart separated by ligature instead of section.

d *e* *f*

FIG. 18.—*d*, diagram of heart with ligature round the venous sinus. *e*, diagram of heart with ligature round middle of auricles. *f*, diagram of heart with ligature in the auriculo-ventricular groove. The pulsations of the ventricle are much slower than those of the auricle and venous sinus. This is indicated by the larger dentation of the outline of the ventricle.

FIG. 19.—Author's diagram of the hypothetical nervous apparatus in the heart. M, motor ganglion. I, inhibitory ganglion. Q, quickening ganglia. O, inhibitory fibres; and S, quickening fibres from the medulla. A, A', B, and C, intermediate apparatus. E, fibres passing from the motor ganglia E to the muscular substance F. For simplicity's sake, only one set of motor ganglia has been represented, but other similar ones are to be supposed to be present in other parts of the heart, and so connected with this set that they all work in unison. It must be remembered that this diagram is purely hypothetical; but if this be carefully borne in mind, the sketch will be found of service in remembering and comparing the action of different poisons on the heart. (Lauder Brunton, *Brit. Med. Journ.*, Dec. 1871, *Collected Papers*, p. 311.)

two nerves pass down the auricular septum to the base of the ventricle, where they end in two ganglia usually called Bidder's ganglia. (Fig. 15.) The origination of rhythmic impulses, their conduction in the heart, and their regulation were regarded as due to the nerves. The experiments of Stannius on the effects of ligature or section of various parts of the heart seemed to show that the nerves of the venous sinus and ventricle were chiefly motor, and those of the auricle inhibitory. (Figs. 17 and 18.)

Investigation of the Movements of the Frog's Heart.—The

FIG. 20.—Author's instrument for showing the action of heat and cold and of poisons on the frog's heart. It consists of a piece of tin plate or glass three or four inches long and two or three wide, at one end of which an ordinary cork cut square is fastened with sealing-wax in such a manner that it projects half an inch or more beyond the edge of the plate. This serves as a support to a little wooden lever about three inches long, a quarter of an inch broad, and one-eighth of an inch thick. A pin is passed through a hole in the centre of this lever, and runs into the cork, so that the lever swings freely about upon it as on a pivot. The easiest way of making a hole of the proper size is simply to heat the pin red hot, and then to burn a hole in the lever with it. To prevent the lever from sliding along the pin, a minute piece of cardboard is put at each side of it, and oiled to prevent friction. A long, fine bonnet-straw, or section of one, is then fastened by sealing-wax to one end of the lever, and to the other end of the straw a round piece of white paper, cut to the size of a shilling or half-crown, according to convenience, is also fixed by a drop of sealing-wax. The pin, which acts as a pivot, should be just sufficiently beyond the edge of the plate to allow the lever to move freely, and the lever itself should lie flat upon the plate. Its weight, too, increased as it is by the straw and paper flag, would now be too great for the heart to lift, and so it must be counterpoised. This is readily done by clasping a pair of bulldog forceps on the other end. By altering the position of the forceps the weight of the lever can be regulated with great nicety. If the forceps are drawn back as at *c*, the flag is more than counterbalanced, and does not rest on the heart at all; while the position *a* brings the centre of gravity of the forceps in front of the pivot, and increases the pressure of the lever on the heart. The isolated frog's heart is laid under the lever near the pivot, and as it beats the lever oscillates upwards and downwards. When used for demonstrating the action of poisons the wooden lever should be covered with sealing-wax, so as to allow every particle of the poison to be washed off it, and thus prevent any portion from being left behind and interfering with a future experiment. By attaching a small point to the end of the straw in place of the paper flag, tracings may be taken upon smoked paper fixed on a revolving cylinder. The fact that heat accelerates and cold retards the pulsations of the heart is one of fundamental importance, both in regard to a right understanding of the quick pulse, which is one of the most prominent symptoms of fever, and to a correct knowledge of the proper treatment to apply when the heart's action is failing.

It may be shown with the apparatus just described by placing a piece of ice under the tin plate. The pulsations will become slower and slower, and if the room be not too warm the heart may stand completely still in diastole. On removing the ice from the plate the pulsations of the heart become quicker. If a spirit-lamp be now held at some distance below it the heart beats quicker and quicker as the heat increases, until at last it stands still in heat-tetanus. On again cooling it by the ice, its pulsations recommence.

movements of the frog's heart may be investigated either by a simple lever laid upon the ventricle (Fig. 20), or by levers laid

on the sinus auricle and ventricle, or by connecting the ventricle with a small manometer. (Figs. 21, 22, 31, and 170.)

According to Gaskell,[1] who supports his opinion by numerous beautiful experiments, the beat of the heart in cold-blooded

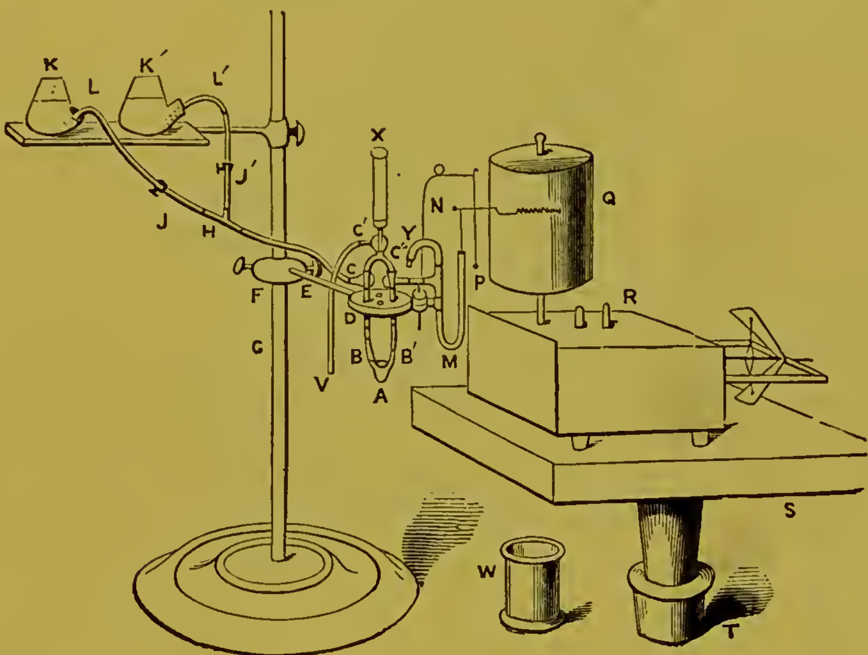


FIG. 21.—Dr H. P. Bowditch's apparatus for experiments on the heart of the frog. A is the frog's heart. B is a cannula tied into the vena cava, and B′ one into the aortic bulb. C, C′, and C″ are three glass stopcocks. By C fresh serum is supplied, by C′ old serum is let out, and C″ allows the communication between the bent tube B C′ B′ and the manometer M to be opened or shut at will. D is a glass plate, through which the bent tube B C′ B′ passes. E is a rod ending in a ring into which D is fitted. F is a nut by which the whole apparatus can be moved up and down on the stand G. H is a T-tube. J and J′ are two clips to stop the flow of serum from K or K′. K and K′ are two fountain-bottles for supplying serum to the heart. K contains pure, and K′ poisoned serum. L and L′ are bent tubes which convey the serum out of K and K′. M is a small manometer. N is the pen or point which swims on the mercury. The horizontal part is made of glass; the vertical rod of esparto grass, with a small piece of sealing-wax at its lower end. The tracing may be made with ink, or with a dry point on smoked paper. P is a small weight which hangs by a piece of unspun silk from a bent wire, and keeps the pen resting on the paper. Q is the revolving cylinder. R is the clockwork, which is provided with one of Foucault's regulators. S is a table, which can be raised or lowered at pleasure, and fixed at any height by the screw T. V is an india-rubber tube, through which the serum is emptied from X. X is a graduated tube, into which the serum is allowed to pass after it has circulated some time. Y is an india-rubber tube, which is generally closed by a clip, but is opened when the apparatus is to be filled, or when we wish to let down the mercury to zero, in order to draw an abscissa. W is a glass vessel, which fits tightly to the under side of D, and protects the heart from external irritation. Into the two holes seen in D tubes may be fitted air-tight, and the heart made to pulsate in an atmosphere of any sort of gas.

vertebrates depends upon the rhythmical power of the muscular tissue in the large veins and sinus being greater than the rhythmical power of the other parts of the heart. He thinks that in all cases, the greater or less rhythmicity of any part of

[1] Gaskell, *Journ. of Physiology*, 1883, vol. iv., p. 80.

the heart depends upon the nature of the muscular fibre of which that part is composed, and not upon the presence or absence of ganglion cells.

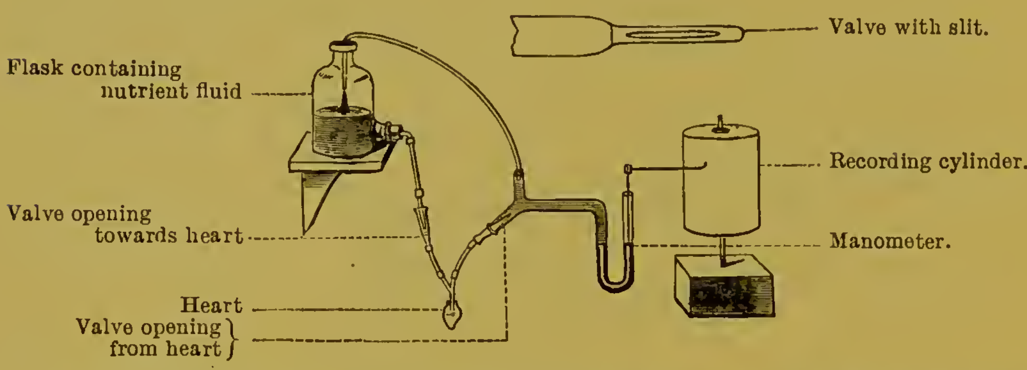


FIG. 22.—Diagram of Williams's apparatus for investigating the action of drugs on the heart of the frog. It consists of a Y-shaped cannula whose stem is divided by a longitudinal septum into two halves, each of which is continuous with the fork on its own side. The stem is inserted through the aorta into the ventricle of the heart, which is kept moist by being dipped in a vessel containing serum or a dilute saline solution. One fork of the Y is connected with a flask containing blood-serum or other nutritive fluid, and the other with a manometer. By means of valves these fluids are made to flow only in one direction. These valves consist of a piece of glass tubing with a slit on one side; over this slit is loosely tied a piece of thin membrane (gold-beater's skin) which covers about three-quarters of the circumference of the tube. This membrane allows fluid to pass readily out of the tube from within outwards, but not from without inwards, any external pressure causing the membrane to become tightly applied to the slit and to close it.

A very useful form of apparatus for investigating the action of drugs on the frog's heart and on the effect of the vagus upon it is made by combining the valves in Williams's apparatus with the apparatus of Ludwig and Coats.

Now, there can be no doubt that living protoplasm can be induced to contract by a constant stimulus, chemical or electrical; such contraction is usually, if not invariably, rhythmical in

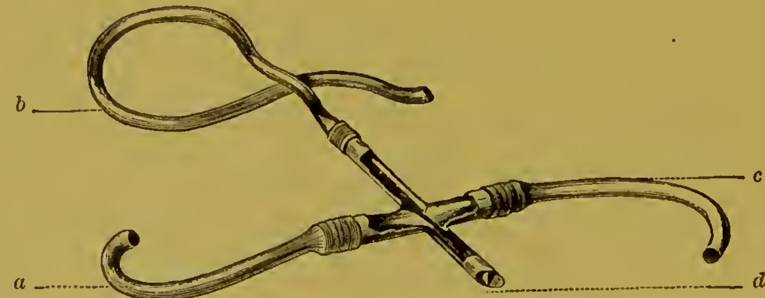


FIG. 23.—Kronecker's perfusion cannula with anterior part removed so as to show the septum. *a* tube for the introduction of fluid into the heart. *b* tube for allowing escape of fluid. *c* tube for connecting with manometer. *d* end for introduction into the heart.

character. Undifferentiated protoplasm has the power both of conducting stimuli and contracting under their influence. As differentiation occurs in muscle and nerve, the contractile power

becomes increased, and excitability diminished in muscle ; whilst in nerves, excitability becomes greatly increased, and contractile power so greatly lessened as to be practically abolished.

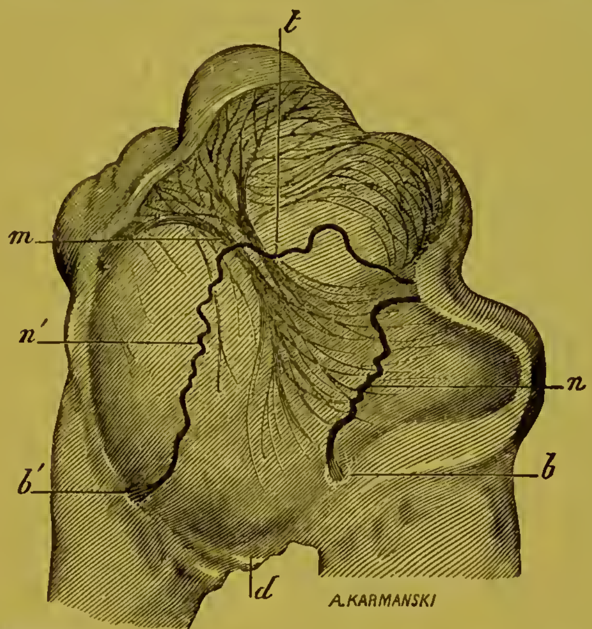


FIG. 24.—View of the auricular septum in the frog (seen from the left side). The nerves are stained with osmic acid. *n* is the posterior, and *n′* the anterior cardiac nerve ; *t* is a horizontal portion of the latter nerve; *b* is the posterior, and *b′* the anterior auriculo-ventricular ganglion ; *m* is a projecting muscular fold. [This figure is taken by the kind permission of my friend, M. Ranvier, from his *Leçons d'Anatomie générale*, Année 1877-78, "Appareils nerveux terminaux," t. 6, p. 79.]

In the embryo the heart pulsates rhythmically before any nerves make their appearance, and according to Gaskell, as the

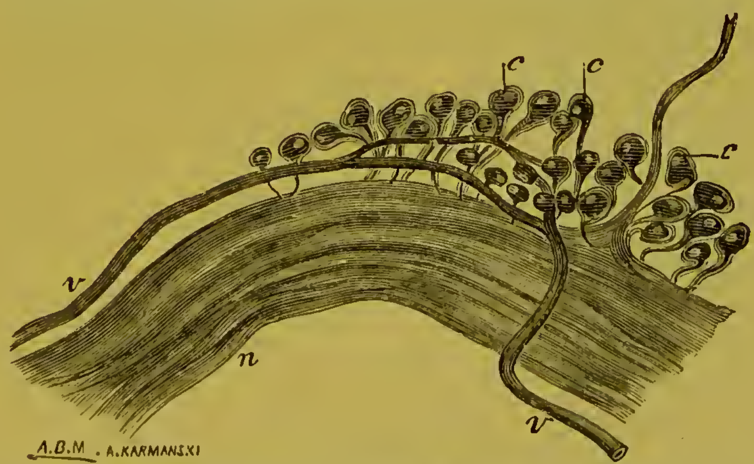


FIG. 25.—Part of the posterior cardiac nerve, highly magnified, showing the ganglia. [Ranvier, *Leçons d'Anatomie générale*, Année 1877-78, p. 106.]

simple tube of the embryonic heart becomes developed the specialised muscular walls acquire a power of more rapid con-

traction. But this nearer approach to striated muscle is made at the expense of the original rhythmical power, so that finally the muscular tissue of the heart becomes differentiated into portions of different kinds and of varying rhythmical power, according to the amount of deviation from the original embryonic muscle. The parts that remain least altered are (1) the large veins, (2) the venous sinus, (3) the junction of the sinus and auricle, (4) the circularly arranged fibres of the auriculo-ventricular groove, and lastly, (5) the bulbus arteriosus.

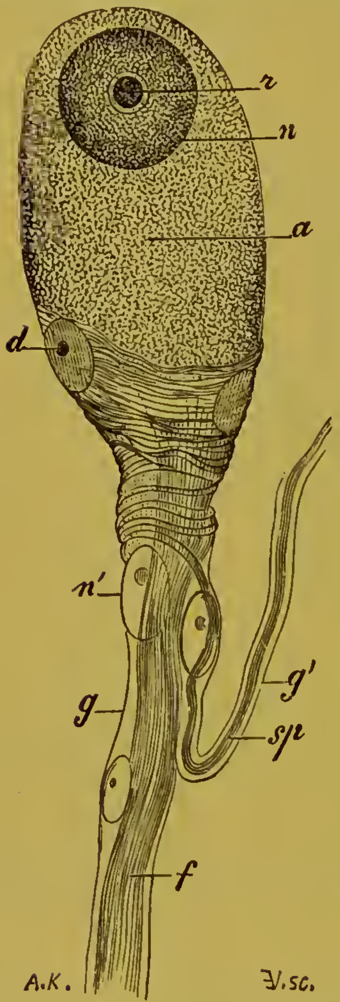


FIG. 26.—Spiral ganglion cell from the pneumogastric of the frog. This figure is not taken from the cells in the cardiac nerves, as in them the connection between the spiral and straight fibres has not been clearly made out, but it is probable that these cells have a structure similar to the one figured (Ranvier, *op. cit.* pp. 114-120). *a* is the cell-body, *n* the nucleus, *r* the nucleolus, *d* nucleus of the capsule, *f* the straight fibre, *g* Henle's sheath, *sp* spiral fibre, *g'* its *gaine*, *n'* nucleus of Henle's sheath. (Ranvier, *Leçons d'Anatomie générale*, Année 1877-78, p. 114.)

The sequence of contraction of the different parts of the heart is also, according to Gaskell, no more dependent upon the presence of ganglion cells than the heart-beat itself, but is due to a peristaltic wave of contraction starting from that part of the heart where the tissue is most automatically rhythmical, travelling most quickly over those parts which approach most nearly in properties to striated muscle, and more slowly over those parts which retain a more embryonic character, viz., the auriculo-ventricular ring and the bulbus arteriosus. According to Gaskell, the cardiac muscle under certain circumstances will act like a nerve, conveying a stimulus to other parts of the heart without contracting itself. His experiments, I think, clearly show that the rhythmical action and normal sequence of contraction in the cavities can be maintained by the more or less differentiated cardiac muscle without ganglia or nerves.

But although this may occur under certain circumstances, more especially when abnormal stimuli are applied, the questions arise—

(1) Is the contraction of the heart, under *normal conditions, due entirely* to its muscular tissue? (2) Are the ganglia it contains entirely superfluous, except in the way of restraining its beats, or maintaining the nutrition of the cardiac muscle?

FIG. 27.—Amœba quickly changing its form. *n* is the nucleus, and *i* is an ingested diatom.

Now, there can be no doubt that the heart of the embryo pulsates rhythmically before any nerves make their appearance. The vesicle in an amœba contracts (Fig. 27), although there are no nerves, and numerous observations go to show that living protoplasm can be induced to contract by a constant stimulus wherever such contraction is capable of observation. But the question is not whether the heart *can* contract rhythmically without nervous action, but, *does it* do this under ordinary circumstances?

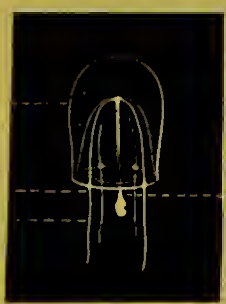


FIG. 28.—Medusa (Sarsia), natural size.

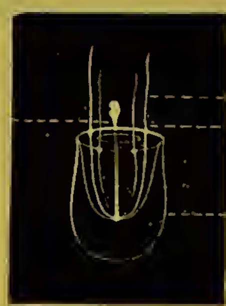


FIG. 29.—Medusa (Sarsia), natural size (inverted). *Cf.* Fig. 30.

Comparison between the Heart and a Medusa.—Experiments of Romanes.—The nervous and muscular structures of the heart are very intimately related, and it is perhaps easier to observe the relationship between protoplasm and nerves in the medusæ, or jelly-fish, where they can be more easily separated. A number of observations were made upon medusæ by Romanes.[1] A medusa consists of a bell-shaped

FIG. 30.—Ventricle of frog's heart with Bidder's ganglia.

[1] Romanes, *Phil. Trans.*, 1877, for 1876, vol. clxvi., p. 269; for 1878, vol. clxvii., p. 659; for 1881, vol. clxxi., p. 161. *Proc. Roy. Soc.*, 1876, p. 143, etc.

piece of contractile protoplasm, from the centre of which a polyp descends, and round the margin of the bell is a nervous

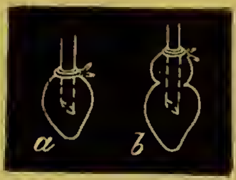


Fig. 31.—Diagram to show the difference in the mode of experimenting with the heart and with the apex alone. In *a* the apex alone is attached to the cannula. In *b* the heart, consisting of ventricle and auricles, or of the venous sinus also, is attached to the cannula.

Fig. 32.—Shows the increasing contractions of the tissue of the medusa when stimulated by repeated weak induction shocks of the same intensity. The first two shocks had no apparent effect, and the first feeble contraction seen in the figure was caused by the third shock. (From a paper by Romanes in *Phil. Trans.*)

gangliated chain and a fringe of mobile tentacles. (Fig. 28.) For the purpose of description, we may put the polyp, for the

Fig. 33.—Increasing contractions of the ventricle of the frog's heart with successive stimuli. (After Bowditch, *Ludwig's Arbeiten.*) *Cf.* Fig. 57.

present, out of account, and if we invert the bell (Fig. 29) we find that it bears a very close resemblance to the ventricle of

Strip of contractile tissue with fringe of tentacles...........

Fig. 34.—Diagram of a medusa (Tiaropsis), about one-third natural size, with a strip of contractile tissue cut from the bell, but left attached at one end.

the frog, which, like it, consists of a contractile portion with ganglia at its margin. (Fig. 30.) When the complete medusa is placed in sea-water, the bell contracts rhythmically, just like a heart. When the nerves are removed by cutting off the marginal strip which contains them, the bell ceases to contract; but it will recommence if a constant stimulus, either chemical or electrical, be applied to it by the addition of acid to the water in which it floats, by alcohol or glycerine dropped on its surface, or by the passage of a constant or interrupted electrical current through it.[1] In this respect it completely resembles the apex of the frog's heart, which ceases to beat when the ganglia at its base are removed, but which will again beat rhythmically if a constant stimulus be applied to it by pressure of fluid in its inside, by the application of stimuli such as dilute acids or alkalies, ammonia, strong saline solution, alcohol, etc., or by the passage of a constant current through it. Moreover, when a stimulus is first applied it may not appear to act, but when applied several times the contractions it induces are stronger and stronger up to a certain maximum (Fig. 32), so as to produce the appearance of a staircase—a phenomenon which was also observed by Bowditch[2] in the case of the heart. (Fig. 33.) When a strip of medusa containing the ganglia is detached only at one end from the animal and is left attached at the other, irritation of the strip will cause a wave to pass along, which is of two kinds. The first is that of contraction in the protoplasm, and the other is a nervous stimulus, which makes itself evident by the movements of the tentacles. (Fig. 34.) These waves generally pass together, the nervous wave being usually a little in front of the contraction wave; but it may also occur, as is shown by the movements of the tentacles, without any contraction-wave in the protoplasm of the strip. This nervous wave is more easily excited than the contraction-wave, so that it may be started by stimuli which are too slight

[1] Romanes, *op. cit.*; and, *Jelly-fish, Star-fish, and Sea-urchins*, p. 175 *et seq.*; vol. iv. of International Scientific Series (Kegan Paul, Trench, & Co., London, 1885).

[2] Bowditch, *Ludwig's Arbeiten*, 1871, p. 155.

to affect the contractile substance, the ganglia apparently being more sensitive than the protoplasm. Apparently, also, for this reason, when the nervous wave reaches the bell it will cause it to contract if there be ganglia still present in the bell; but if these have been removed, the nervous wave has not the power of stimulating the protoplasm in the bell, which, consequently, remains motionless.

The passage of stimuli along the strip may be hindered or prevented by compressing it, by partially dividing it so as to narrow it, or by straining it so as to injure it, or by poisons, and as one would expect from different kinds of injury, sometimes the contraction wave is blocked first and sometimes the nervous wave.

The effects of poisons on medusæ were localised by Romanes (*Phil. Trans.* for 1876 and 1877) in two ways. One way was to divide the medusa almost into two halves, connected only by a narrow strip of tissue. These halves were plunged into two beakers filled with sea-water, pure in one and poisoned in the other. The connecting strip rested upon the edges of the beaker. (Fig. 35.) When curare was employed in this way, it was found to paralyse the motor nerves, while it left the sensory nerves capable of action. Thus, on nipping the half of a medusa which was plunged in the curare solution, it remained absolutely motionless, while the other half at once responded by a peculiar contraction to the stimulus.

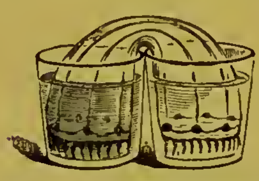


FIG. 35.—Diagrammatic representation of the method of localising the action of poisons on medusæ. One vessel contains normal sea-water; another contains poisoned sea-water, which is shaded in order to distinguish it.

Nicotine appeared to paralyse the ganglionic structures and not the nerves.

The rhythmical movements of medusæ depend upon the ganglia: when these are all cut off the movements cease, but if only one be left the movements continue. In the medusa divided into two halves, as already described, it is evident that if the ganglia are removed from one half, or one half rendered functionally inactive by poison, that half will still continue to contract, so long as it remains connected with the other half, but will cease to move when it is completely divided from the half

which still contains ganglia. The effect of nicotine is such as one would expect if the poison paralyses the ganglia, for it is found that when one half of a medusa is steeped in water containing nicotine, both halves still continue to pulsate rhythmically; so soon as the connecting band of tissue is divided, the

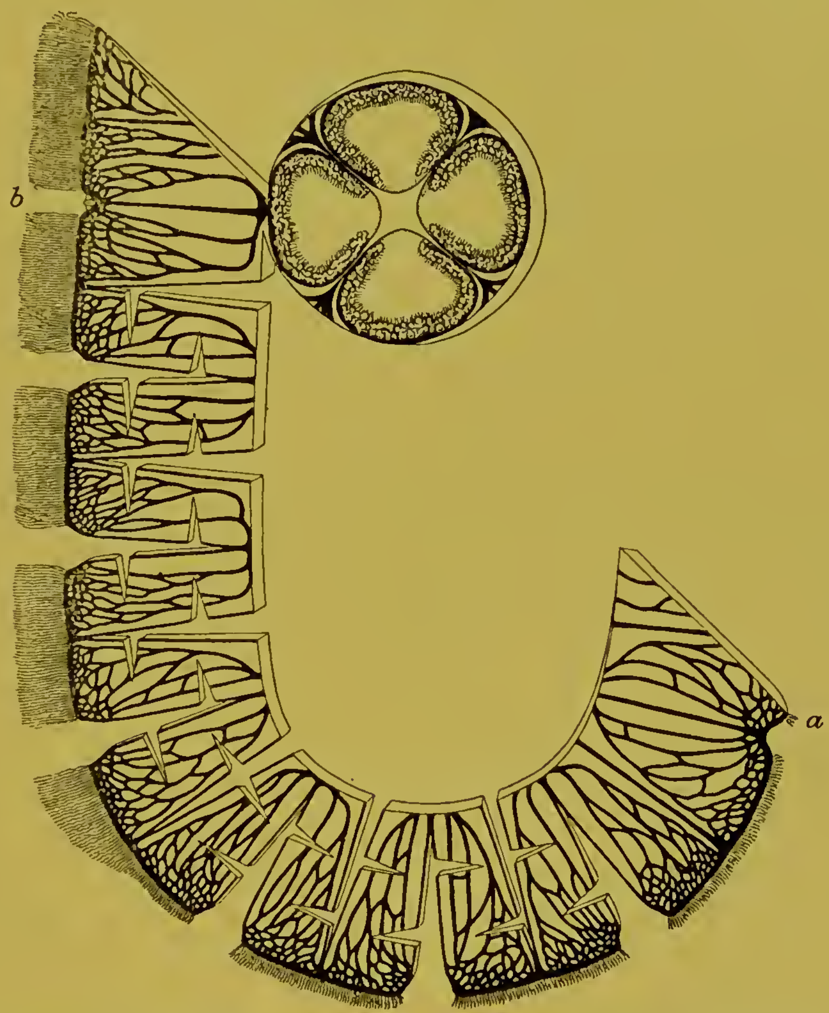


FIG. 36.—Medusa (*Aurelia aurita*) from which the ganglia have been removed, and the bell cut into a long strip with cross cuts to block the passage of contractile and tentacular waves. The polypite is at the other end. *a* and *b* are at the two ends of the strip. When stimulation was applied to either *a* or *b*, a tentacular wave started from that point and travelled all the way to the other end. (After Romanes, *Phil. Trans.* for the year 1877, vol. clxvii., part ii., p. 719, and Plate 31.)

poisoned half at once ceases to move, while the other half continues to pulsate.

The second way in which Romanes localised the action of poisons on medusæ was by applying them to a strip of contractile tissue. (Fig. 36.) He found that various poisons applied to the

strip, or injected into it, caused a blockage of contractile waves, preceded by a progressive slowing of the rate of transmission along the poisoned part. . Chloroform, ether, alcohol, morphine, strychnine, and curare all have this effect.

When the block is only partial, it may happen that three waves come up to it before one can pass across, as if each wave had prepared the passage for the remainder, and at last the third or fourth overcomes the obstacle.

Gaskell has noticed a similar effect from compression of the auriculo-ventricular groove in the frog's heart, and the same thing is also observed in certain cases of cardiac disease and from the action of cardiac poisons. (Fig. 37.)

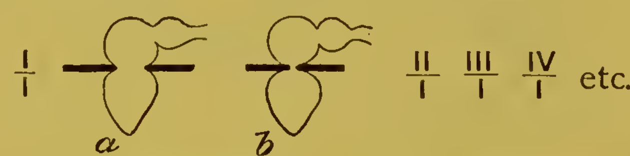


FIG. 37.—Diagram to illustrate Gaskell's experiment. At *a* the jaws of the clamp hold the heart without compressing it, and each beat of the auricle is succeeded by one of the ventricle, as shown by the figure $\frac{\mathrm{I}}{\mathrm{I}}$. At *b* the heart is compressed, and its rhythm disturbed, so that one beat of the ventricle only occurs for several of the auricles. This is indicated by the Roman numbers, the upper line of which shows the number of auricular, and the lower of ventricular beats.

Transmission of Stimuli in the Heart.—If (1) all the rhythmical power of the auricles and ventricles and (2) all their co-ordinated action are dependent only on the cardiac muscle, one would say that it was quite unnecessary to have such an extraordinary abundance of nerves as exists in the heart. One would be inclined to say that they are superabundant and useless, but one cannot help remembering that years ago the liver was looked upon as a totally unimportant organ, whose only function it was to secrete a little bile. Fuller knowledge has shown that instead of being useless, it is one of the most important organs in the body ; and in all probability increased knowledge will again show the importance of the cardiac nerves.[1]

In order that we may understand the object of these nerves

[1] The importance of the cardiac ganglia in originating the beats of the heart has been prominently brought forward since these lectures were given, by Dogiel and Archangelsky, *Pflüger's Archiv*, July 1906, vol. cxiii., pp. 1-96.

more easily, I may perhaps be allowed to employ a simple comparison. A railway train, when once started, usually proceeds from station to station without interference; but alongside the rail, or overhead, run the telegraph wires, and at any station the progress of the train may be stopped by a message sent by the telegraph. You will notice also that in many railways an electric bell rings before the train actually appears, so that all preparations may be made for its arrival. In the heart the transmission of stimuli by the cardiac muscle would correspond to the passage of the train; the transmission by the nerves would correspond to the telegraph, by which the movement of the ventricle might either be stopped, even after an impulse had been sent on from the auricle, or, on the other hand, the ventricle might be prepared to respond more quickly to the stimulus passing from the auricle. The advantage of such a preparation is evident from Romanes' experiments, in which stimuli did not always produce the proper effect unless they had been preceded by another stimulus which prepared the protoplasm to react.

Nervous and Muscular Conduction in the Heart.—Acting upon the idea which I have tried to illustrate to you by the train and the telegraph, Dr Cash and I endeavoured to find out whether we were able, by stimulation of the venous sinus or of the auricle in the excised frog's heart, to produce such changes in the ventricular contraction as one might expect if there were really two lines of communication, nervous and muscular, instead of muscular alone. The bearing of this upon cardiac irregularity is naturally of the greatest importance.

I have already mentioned that there is a refractory period during which the ventricle does not appear to react to stimulation. This was discovered by Kronecker and Marey, and the time relations of this period, as well as the electrical changes which accompany it, were investigated by Sir John Burdon-Sanderson and Mr Page.[1]

Experiments of Brunton and Cash.—The results that Cash and I obtained agree with those of previous observers, and I show you here some tracings to illustrate this point. In regard to these tracings, as well as to all the others contained in the

[1] Burdon-Sanderson and Page, *Roy. Soc. Proc.*, 1878, p. 410; 1880, p. 373.

paper from which it is taken, I may say that the investigation extended over nearly *three years*, that the number of tracings was enormous, and that our conclusions were founded upon very numerous observations, and not merely upon the small pieces which are printed in the paper, which were cut down to the lowest possible minimum, on account of the expense of printing. These illustrations are merely to show the points which we made out, but are not to be regarded as being the basis upon which our conclusions were founded.[1] I wish to lay particular stress upon this point, lest the small number of tracings printed in the paper should lead other workers on this subject to reject our conclusions as being founded on insufficient data, when in fact the number of experiments was very large.

Irritation of the ventricle at the commencement of systole nearly up to its maximum, *i.e.* during the refractory period, has no effect at all. (Fig. 38, *a*, *b*.) Stimulation from the maximum of systole to its end causes a reduplication of the systole (Fig. 39), and in the diastole it does the same almost immediately. (Fig. 40.)

When the auricle is stimulated, the stimulation may cause a second auricular beat immediately after the first. (Fig. 41.) This second beat, in place of being succeeded by a ventricular pulse, prevents the next ventricular beat from following in order, just as two trains may be started in almost immediate succession from one station, and a telegraphic message may be sent on at the same time that the second train is not to be allowed to pass the next station.

When the venous sinus was stimulated it produced reduplication of the auricular beat, but absence of the ventricular beat which should have succeeded it, in much the same way. (Fig. 42.)

Conduction of Impulses both by Muscle and Nerves.—These experiments, which were not only very numerous but very varied, seemed to us to show that, just as in a medusa, there are

[1] Brunton and Cash, "On electrical stimulation of the Frog's Heart, and its modification by cold, heat, and the action of drugs," *Roy. Soc. Proc.*, 1881, vol. xxxii., No. 214, and 1883, vol. 35, No. 227, p. 455. The instrument with which the observations were made was devised by Dr Cash, and described by him, *Journ. of Physiology*, iv., 1883, p. 128.

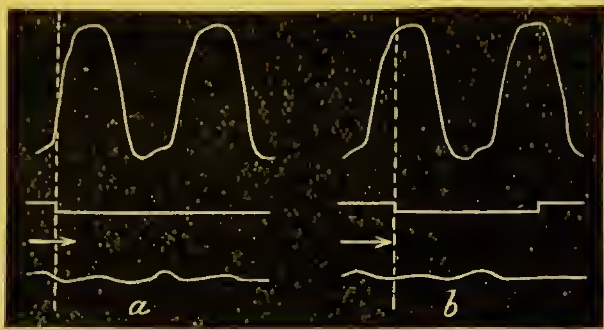


FIG. 38.—Tracing showing the effect of electrical stimulation upon the ventricle of the frog's heart. The upper line shows the ventricular contraction, the lower one the auricular contraction, and the middle line the time of application of the electrical stimulus. The depression shows the time of breaking, and the ascent the time of again making the current. In most of these tracings only the break is effective as a stimulus. The arrow shows the direction in which the tracing is to be read. The dotted line shows more exactly the exact time in regard to the systole at which the stimulus was applied. In both a and b the stimulus falls within the refractory period, and produces no effect. In this and the following tracings the movements of the ventricle and auricle were registered by levers resting on them.

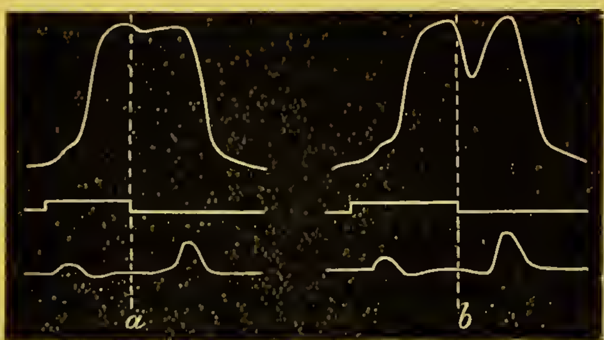


FIG. 39.—Effect of electrical stimulation of the frog's ventricle after the refractory period has passed. It shows different forms of reduplication; also, that the auricular systole following the stimulation is nearly coincident with, or even a little later than, the ventricular systole, instead of preceding it in the usual way.

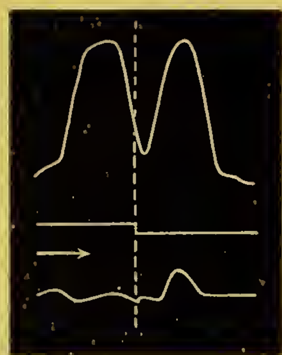


FIG. 40.—Shows reduplication of the beat of the ventricle from stimulation applied to it during the diastole.

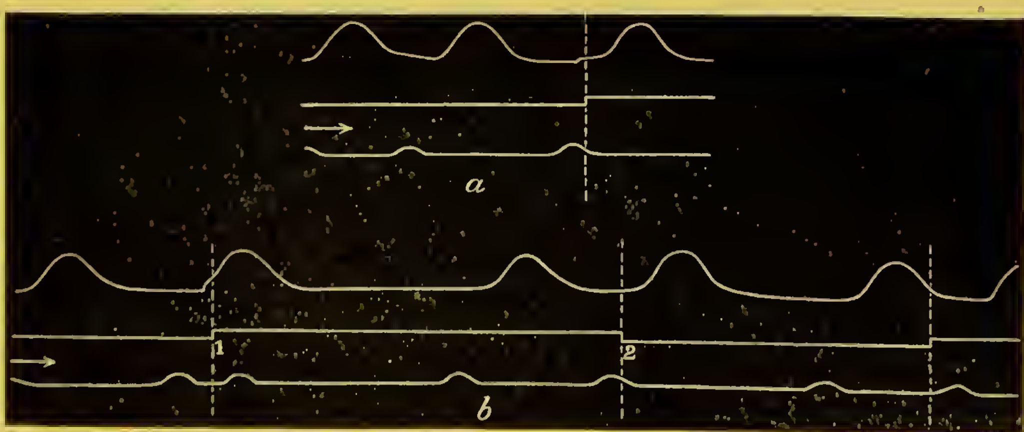


FIG. 41.—Shows effect of stimulation of the auricle on the beats of the auricle itself and of the ventricle. The weaker stimulus in a produces no reduplication of the auricular beat, although other experiments showed that it usually produced a very prolonged pause. In the lower tracing b, stimulation had various effects, according to the time of the auricular systole at which it was applied. At b 1 it caused reduplication of the auricular beat, with omission of the ventricular beat; at 2 it only produces prolongation of diastole in both auricle and ventricle, and the third had no apparent effect.

in the heart two distinct channels, the nervous as well as the muscular, by which stimuli are conducted from one part of

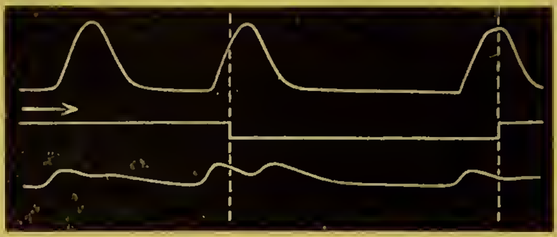


FIG. 42.—Shows the effect of stimulation of the venous sinus. It is much more sensitive to stimulation than either the auricle or ventricle, so stimuli will produce an effect npon it, although too weak to act on either auricle or ventricle. It causes reduplication of the auricular and omission of the ventricular beat, like stimulation of the auricle at *a*, Fig. 40. In the experiment of which this is a tracing a minimal stimulus was employed, and only the opening of the current was effective. The opening is indicated by the sinking of the continuous line, and its closing by the rise. The closing shock produced no effect. The relation between the time of stimulation and the auricular contraction (lower tracing) and the ventricular contraction (upper tracing) is shown by the dotted lines.

FIG. 43.—Periodic rhythm of the heart, the pulsations occurring in groups separated by intervals of complete quiescence. (After Luciani, *Ludwig's Arbeiten*, 1872.)

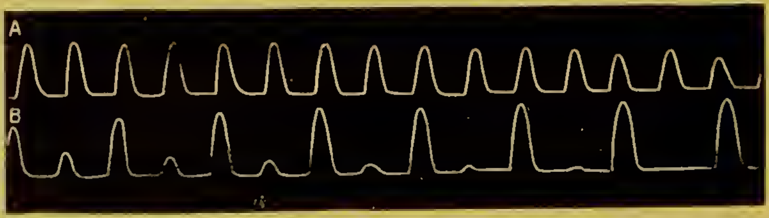


FIG. 44.—Tracing of the pulsations of a ventricle separated from the auricles by section at the auriculo-ventricular groove. (After Ranvier, *Leçons*, 1877-78.)

the heart to another, and that the nervous conduction may interfere with the muscular conduction.[1]

[1] This explanation is in accord with the conducting function of the bundle of His, or the fibres of Purkinje, which may be regarded as neuro-muscular. Since these lectures were given, the conducting function of the

Another experiment which is very striking, is that of Kronecker and Schmey,[1] who found that by puncturing a point in the septum of the ventricles, at about the junction of its upper third with its lower two-thirds, the rhythmical action of the heart is stopped immediately, and little, quivering tremors are to be seen all over the ventricle, but, while the fibres are contracting, the heart, as a whole, is quiescent. It is not always easy to hit this point. My friend, Professor Kronecker, tells me that he has sometimes struck it at the first attempt, but on other occasions he has tried more than thirty, and I think that when he showed it to me it was quite fifty times, but the difference between the time when he did not strike it and the time when he did so was most extraordinary. The

muscular bundle described by Stanley Kent in 1892 (*Proc. Physiol. Soc.*, Nov. 1892), and by William His, junior, in 1893, which connects the auricles and ventricles, has attracted much attention, and the neuro-muscular fibres described by Purkinje have also come again more into notice. The bundle of His is thus described by him: "The bundle springs from the posterior wall of the right auricle, near the auricular septum, in the auriculo-ventricular sulcus, is attached to the superior edge of the muscle forming the ventricular septum, and exchanges fibres with it. It passes forwards on the ventricular septum, till near the aorta it divides into a right and left branch, the latter of which ends in the base of the aortic cusp of the mitral valve. (William His, junior, *Arbeiten aus der Medicinischen Klinik zu Leipzig*, *herausgegeben von* Dr H. Curshmann, Leipzig, F. C. Vogel, 1893, p. 23). No nerve trunks are to be found in this bundle (Ritzer, quoted by Erlanger), but it contains nerve fibres (Tawara and Aschoff, *Zeitsch. f. Physiol.*, 1905, xix., p. 298), and the muscle fibres are very fine and of an embryonal character. The ventricular part of the bundle passes as a finely ramifying system to the ventricular wall and papillary muscles, and consists of Purkinje's fibres. These fibres consist of cells which are only striated on their periphery, and may be regarded as only partially differentiated, and possessing the properties of nerve as well as muscle (Ranvier, *Leçons d'Anatomie Générale*, *Système Musculaire*, Paris, 1850, p. 300). They appear to conduct the stimuli from the auricle to the ventricle in mammalian hearts more slowly than nerves. When the conducting power of the bundle of His is destroyed by clamping it, similar disturbances of the relation between the rhythm of the auricles and ventricles are produced, as Gaskell observed in the frog's heart (Stanley Kent, *Journ. of Physiol.*, 1893, vol. xiv., p. 250; and Erlanger, *Journ. of Experimental Medicine*, vol. viii., p. 8). Their degeneration produces heart block and intermittence of the pulse.

[1] Kronecker and Schmey, *Sitz. ber. d. Akad. d. Wiss. zu Berlin*, 1884, s. 87.

effect of the thin needle penetrating the heart appeared to be *nil* until he struck the proper point, and then the rhythmical power was instantly and completely abolished. The effect on the heart was similar to that of puncture of the *nœud vital* in the fourth ventricle upon respiration.

It is almost impossible to explain such a result as this on the idea that rhythmical contractility is dependent only upon the

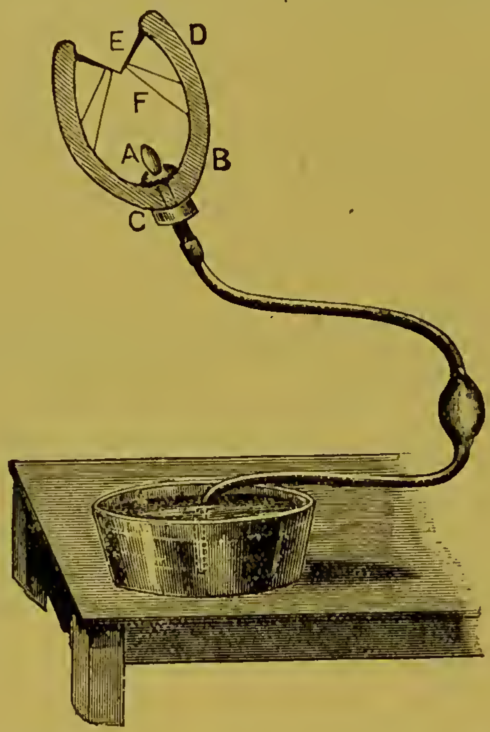


FIG. 45.—Diagram of the author's instrument for ascertaining the competence of the mitral or tricuspid valves, and illustrating the action of the musculi papillares. D is a section of the heart, with the valves (E) and the chordæ tendineæ (F). The nozzle (A) of an enema apparatus is taken off and its longer end thrust from the inside through the ventricular wall (B), and is there kept in place by the flange on the inside and a thick rubber ring (C) on the outside. On pumping water gently in, the valves (E) will be seen to float upon the surface of the water, then to become firmly opposed or screwed together, and only when the ventricle is forcibly distended or distorted by unequal pressure on its sides do the valves leak. (Lauder Brunton, *St Bartholomew's Hospital Reports*, 1878, vol. xv., p. 283.)

muscular structure; but one can quite readily understand it on the other idea, viz., that there are two controlling conditions in the heart—(1) the nervous and (2) the muscular, and that these may, under certain circumstances, *interfere* with each other, and thus abolish contraction more or less completely, and produce intermittence or irregularity of the pulse.

Valves of the Heart.—All these experiments have a bearing

upon the rhythm of the heart, as we shall afterwards see, but the more common diseases of the heart are really those

FIG. 46.—Heart in full systole, showing the mitral and tricuspid orifices so diminished by the muscular contraction that the valves close them easily.

FIG. 47.—The same heart as in Fig. 46, from another point of view.

associated with imperfection of the valves. If the valves were not present, the blood, instead of being forced steadily onward,

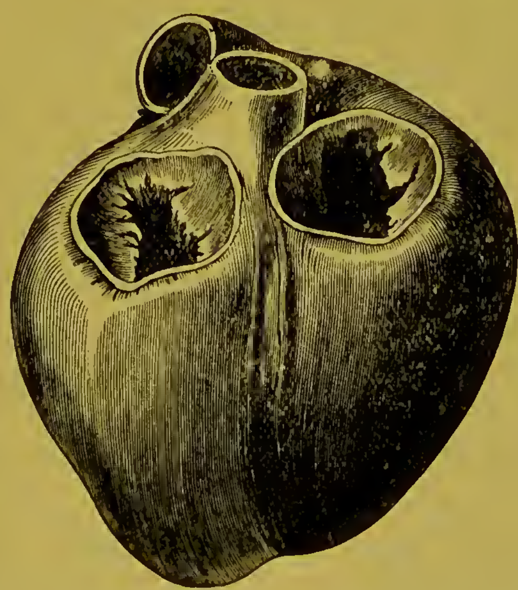


FIG. 48.—Heart fully distended, showing insufficiency of the valves to close the mitral and tricuspid orifices.

would tend to regurgitate, but the presence of the valves prevents this. In the aorta and pulmonary artery we have

three segments which are simply brought together like those of an ordinary pump, by the pressure within the artery when the ventricle ceases to contract. In the valves which separate the auricle from the ventricle, we require something more than this, because the valves are large, and when the walls of the ventricle approximate during systole the thin valves would be driven back into the auricle, were it not that they are attached by fine cords and by muscular columns which, contracting with the rest of the ventricle, draw the valves downwards and prevent them from being forced back into the auricles. (Fig. 45.) The action of these valves is aided by the contraction of the muscular fibres around the auriculo-ventricular orifices, which are greatly lessened in diameter, so much so that one might say that even imperfect valves might close them (Figs. 46 and 47); whereas when the cardiac contraction is feeble the orifices may be too large to be completely covered, and thus a certain amount of regurgitation may take place even though the valves themselves are perfectly healthy (Fig. 48).

LECTURE II

Sounds of the Heart—Double Nature of the Heart—Right Ventricle—Aorta—Arteries and Capillaries—Vaso-motor Nerves—Dilating Nerves—Elongation of Muscle (?)—Rhythmical Contraction of Vessels—Stimulation of Vessels from without—Stimulation of Vessels from within—Effect of Heat and Cold on the Circulation—Effect of Heat and Cold on the Pulmonary Capillaries—Schema of the Circulation—Kymographs—Blood Pressure in Animals—Blood Pressure in Man—Measurement of the Blood Pressure in Man—Instruments for Measuring the Blood Pressure in Man: By Pressure on an Artery; By Pressure on a Finger or Limb; Sphygmomanometers of Hérisson, Waller, Von Basch, Potain, and Oliver; Instruments of Marey, Mosso, and Gärtner.

Sounds of the Heart.—The closure of the valves in the heart occasions sounds which can be heard by putting the ear to the chest wall, and they can be still better localised by the use of a stethoscope. When we do this, we hear sounds which are well imitated by the syllables "lub-dup," close to one another. These syllables follow one another quickly, and then comes an interval, which represents the diastole of the heart. The credit of showing that the second sound, "dup," is caused by the closure of the aortic valves, belongs to C. J. B. Williams, and the Committee in which he, Hale, and Glendinning took part.[1] They showed that when the aortic valves were destroyed, the sound disappeared. The causation of the first sound, however, has given rise to a great deal of discussion. Some authors have considered it to be a valvular sound, and due to the flapping together of the auriculo-ventricular valves; whilst others, like Magendie, have thought it to be caused by the striking of the apex against the chest wall, and yet others have looked upon it

[1] *Sixth Report of the British Association*, 1836, p. 265.

as being a muscular sound, due to the ventricular contraction. There seems to be little doubt now, from the experiments of Ludwig, Dogiel,[1] and others, that the first sound is chiefly muscular, and brought about by the contraction of the ventricle; but the experiments of Ottomar Bayer[2] in Ludwig's laboratory demonstrated that, apart from the muscular sound, a distinct valvular click could be obtained by the closure of the auriculo-ventricular valves in a dead heart, whilst Williams and his confrères found, in addition, that the first sound was intensified by allowing the exposed heart to beat against a piece of board. We may thus consider that there are three factors which all take part in the production of the first sound, viz., (1) the ventricular contraction, (2) the closure of the auriculo-ventricular valves, and (3) the impulse of the apex against the chest wall.

As we would expect, the first sound is heard most loudly over the apex, which is the point of the chest wall nearest to the ventricle. The second sound is heard more sharply over the aortic valves, which lie beneath the left side of the sternum, at about the level of the third intercostal space, but is heard still better at the point where the aorta most nearly approaches the sternum at its right edge, and at the level of the second intercostal space or third costal cartilage.

Alterations in the Second Sound.—When we hear a door slammed loudly, we know that it is closed quickly in consequence of the application of unusual force; and just as we would expect, when tension is high in the aorta the second sound is louder than usual, or as it is termed, is accentuated, and this accentuation of the second sound over the aorta is one of great clinical importance, indicating, as it does, high arterial tension or aortic atheroma or aneurism.

Alteration in the First Sound.—The causation of the first sound being more complex, alterations in it occur from a greater number of causes. As it is to a great extent a muscular sound, we should naturally expect that weakness of the cardiac muscle, such as occurs in fevers, would lessen the sound, and this is exactly what happens. In cases of typhoid fever, when the first

[1] *Ludwig's Arbeiten*, 1878, p. 78.
[2] O. Bayer, *Arch. f. Heilk.*, xi., p. 157.

sound becomes inaudible we know that the heart is so weak as to render the prognosis grave. But it would appear that it is not mere muscular strength which causes the sound to become loud: it is rather rapidity of contraction; and even a comparatively feeble heart may have a loud, clear first sound if the tension in the aorta is low, or, in other words, if the resistance it has to overcome is small, so that it can contract rapidly. When the arterial tension is high, and the resistance to be overcome is consequently great, the muscular walls of the ventricle contract comparatively slowly, and even when hypertrophied far beyond their normal size, they may give rise to a sound weaker and duller than normal. Of course, the rapid contraction not only gives rise to a greater muscular sound, but it closes the auriculo-ventricular valves more sharply, and thus increases also the valvular part of the first sound. And yet, again, a heart contracting quickly gives a sharp, or as it is sometimes called, a slapping impulse to the chest wall, while the more powerfully hypertrophied heart, acting on a greater resistance, gives a thudding or pushing impulse not likely to cause so much resonance, and thus the sound will again be diminished. The last factor in the production of the first sound in the heart may also be lessened by a thick layer of lung between the ventricle and the chest wall, as in emphysema, and the lung will also tend to deaden the sound by acting as a non-conductor between the ventricle and the ear.

Cardiac Murmurs.—When the aortic valves are destroyed, the sharp "dup" which their closure causes in health disappears, and is replaced by a bruit or murmur. You will most easily understand this by trying to say "dup" with your lips apart, and you will then find that without thinking of it you reproduce the sounds actually heard in aortic incompetency. When it is slight, the closure of the valves is still heard, but is followed by a whiff, as when you say "duff," and in aortic regurgitation the sounds are like "lub-duff." The same happens with the mitral valve, and when this valve alone is incompetent, the sounds of the heart are like "luff-dup"—"luff-dup." When both valves are slightly incompetent, the sounds are like "luff-duff"—"luff-duff"; and when both

valves are very incompetent, a bellows murmur occurs, like "oho-oho."

Double nature of the Heart.—For the sake of simplicity, I have spoken hitherto of the heart as if it consisted only of the left side, but we have in man, as in other mammals, really two hearts joined together in one, the right and the left; the right sending the blood through the lungs for the purpose of aërating it, and the left sending the blood through the body in order to nourish the tissues. Both hearts receive the blood from the large veins into the auricles, which, contracting, send it on to the ventricles, and thence it is propelled by the right ventricle into the pulmonary artery, and by the left ventricle into the aorta. As I mentioned before, both the vena cava and the pulmonary veins have the power of rhythmically independent pulsation apart from the auricle, and the cardiac beat may frequently, though probably not always, originate in them.[1]

Right Ventricle.—The resistance which the right ventricle has to overcome in driving the blood through the pulmonary artery is only about one-third that presented by the aorta, and, consequently, the right ventricle is only about one-third the strength of the left. The tricuspid valves, which separate the right ventricle from the right auricle, are much more easily rendered incompetent by distension of the ventricle than are the mitral valves, and this tendency to incompetency has been regarded, and I think with truth, as a safety valve, preventing the stoppage of the right ventricle by over-distension, and allowing the blood to pass back into the venous reservoirs, of which I have already spoken.

Aorta.—On looking at the aorta, one would say that it is entirely composed of fibrous tissue, and consequently is not likely to possess any contractile power, and yet it would appear to have such a power, for in the case of a criminal executed at Würzburg, it was found to contract on the application of electricity shortly after death.[2]

Arteries and Capillaries.—As we pass down the arterial

[1] *Vide* p. 17.

[2] *Verhandl. d. Med. Phys. Gesellsch.*, Würzburg, 1854, p. 1; and *Schmidt's Jahrb.*, vol. lxxxv., p. 12.

system the muscular fibres become more developed, and in the arterioles we find a continuous muscular layer, while in the capillaries we have nothing but contractile cells. Just as in the case of the heart, where we have two kinds of nerves having an opposing action, so we have in the vessels nerves which cause contraction and others which cause dilatation. When working with Schweigger-Seidel in Ludwig's laboratory in 1869, I made a number of observations on the nerves of the arterioles and veins, but these were not published, as I did not discover anything new. I tried in vain to find any evidence of nerve fibres entering the muscular cells of the arterioles, but could never observe it. All that I could find was a regular network of minute nervous fibrils running over the surface of the muscular layer. At the points where these fibrils cross there are small thickenings or knots, but nothing at all like ganglion cells.

Vaso-motor Nerves. — Dilating Nerves. — Elongation of Muscle (?).—The vaso-motor system, as I have already said, has its chief centre in the medulla oblongata, but it has subsidiary centres in the spinal cord itself, and in the ganglionic chain of the sympathetic. When the centres or nervous trunks of the vaso-motor nerves are irritated, the vessels contract; but there are other nerves which when irritated cause dilatation instead of contraction, and this dilatation is greater than that which occurs on the division of the vaso-motor fibres supplying the vessel.[1] This fact is generally explained by supposing that irritation of the dilating nerves has an inhibitory action upon local vaso-motor mechanisms close to the vessels, though, for my own part, I should be inclined to accept the much simpler explanation that a transverse as well as a longitudinal contraction may occur in the muscular cells of the arterioles, and such a transverse contraction would elongate each cell and dilate the vessel (Fig. 49), just as the longitudinal contraction would shorten and thicken the cell and thus contract the vessel. In many instances, dilatation or dilation is connected with peripheral ganglia; for example, in the sub-maxillary gland and in the nervi erigentes, but that it is always due to such nervous causation is, I think,

[1] *Vide* Tigerstedt, *Lehrb. d. Physiol. d. Kreislaufs*, p. 512 (Leipzig; Veit & Co., 1893).

doubtful. For a good while the contractility of capillaries was doubted, but the observations of Stricker and others have now, I think, put this fact beyond dispute.[1] When working under Ludwig's direction I also noticed that local irritation would sometimes cause, not contraction, but dilatation of an arteriole.[2] Similar observations were made by Gunning and Cohnheim in the frog; so that, just as the effect of nerves upon the heart itself, to the exclusion of muscular irritability, is now recognised to be wrong, so in all probability the properties of the muscular elements of the arterioles, like those of the heart, will by and by receive more attention than they have hitherto done.

FIG. 49.—Diagram to illustrate the hypothetical transverse contraction of muscle. (*a*) Muscle in relaxed condition, (*b*) in contraction, (*c*) in elongation.

Rhythmical Contraction of Vessels.—Rhythmical contraction of the veins was observed to exist by Wharton Jones,[3] Schiff,[4] and Vulpian.[5] The arteries also contract rhythmically under the influence of the vaso-motor centre, and give rise to periodic pulsations which are coincident with respiration. In addition to these, however, the arteries themselves pulsate[6] periodically.[7] It is difficult to see this pulsation in healthy people, but it can be well observed, as a rule, in patients suffering from aortic regurgitation. In such cases the face is usually pale, but if the finger-nail be rapidly drawn across the forehead, a red streak appears which alternately widens and narrows, and this movement on careful observation will be seen to show three rhythms. The first coincides with the pulse, and occurs between sixty and seventy times per minute; the second with

[1] Stricker, *Sitz. Ber. d. k. k. Akad. d. Wiss. Math.-nat. Cl.*, 1865, 41, Abt. 2-3, 51; 1866, 52; 1876, Abt. 3, 316.

[2] Lauder Brunton, *Ludwig's Arbeiten*, 4ter Jahrg.; and, *Collected Papers on Circulation* (First Series, pp. 160, 178).

[3] Wharton Jones, *Phil. Trans.*, 1842, p. 131.

[4] Schiff, *Arch. d. ges. Physiol.*, xxvi., p. 456.

[5] Vulpian, *Mem. Soc. Biol.*, iii., 1856, p. 223, and 1858, p. 3.

[6] Schiff, *Arch. f. Physiol. Heilk.* 1854, t. xiii., p. 521.

[7] Lauder Brunton, *Ludwig's Arbeiten*, 4ter Jahrg., 1869.

respiration, about eighteen or twenty times per minute ; and the third, or capillary rhythm, is only about three times per minute.[1]

Stimulation of Blood-vessels from without.—It is difficult to explain the various local alterations of the circulation, if we look entirely to the nervous system for an explanation of them ; whereas the explanation is easy if we acknowledge the power of vessels to contract or dilate from alterations in their contractile element apart from the nervous, although, just as in the heart, we must fully recognise the enormous influence of the

FIG. 50 —Vessels in the web of a frog's foot in the normal condition. (After Lister.)

nervous system upon the vessels. Thus, when we apply a mustard poultice to the skin the rapid dilatation of the vessels and consequent redness which immediately follows the application are probably due to nervous influence, but the permanent redness, which may remain for several days, is more likely to be due to a local alteration in the vessels themselves. (Fig. 51.)

Stimulation of Vessels from within.—A still more important question, however, than the effect of irritation of the vessels from the outside, is that of stimulation from the inside by various products of tissue waste or by strain. In chronic interstitial

[1] Lauder Brunton, *Journ. of Physiol.*, 1884, vol. v., p. 14.

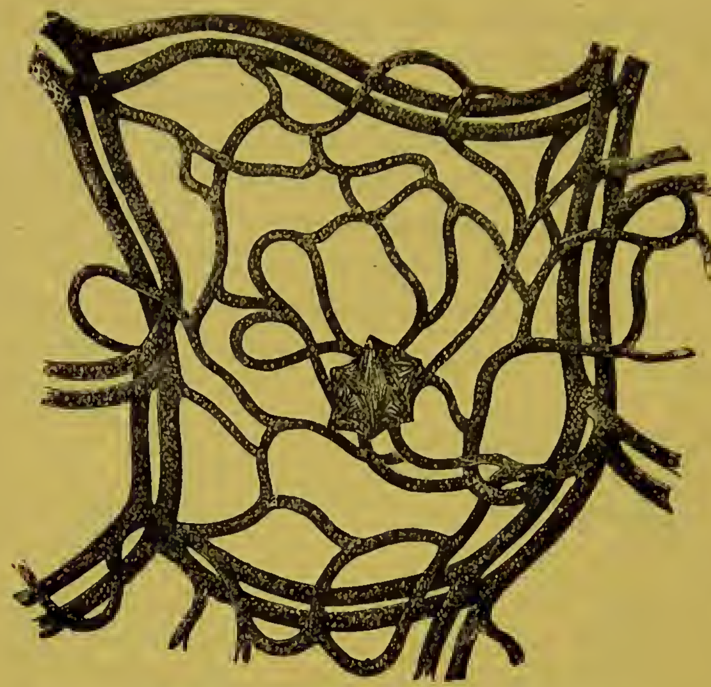


FIG. 51.—The same vessels as in Fig. 50, after irritation

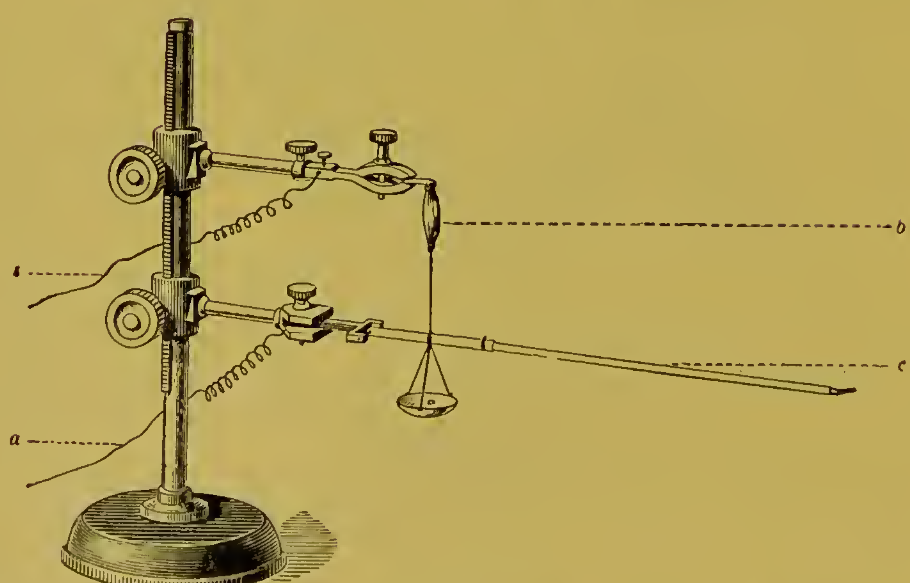


FIG. 52.—Apparatus for registering muscular contraction. It consists of an upright stand on which two horizontal bars may be moved by a rack and pinion. The upper bar ends in a clamp, the lower carries a delicate lever, the part near the hinge being of metal, and the part beyond of light wood tipped with quill or tinfoil. *a*, *a*, Wires for exciting muscle; *b*, muscle; *c*, writing lever. In the figure no arrangement is shown for exciting the nerve, and for the sake of simplicity the weight is shown directly under the muscle. In actual experiment, however, the weight should be applied close to the axle, or on it, so as to lessen oscillation due to the inertia of the lever.

nephritis the blood pressure tends to rise gradually, so as to threaten life either from cardiac failure or from arterial rupture. This high tension appears to commence by increased resistance to the passage of blood through the arterioles and capillaries. By some it is attributed to chronic contraction of the arterioles with hypertrophy of their muscular walls, by others to a fibroid

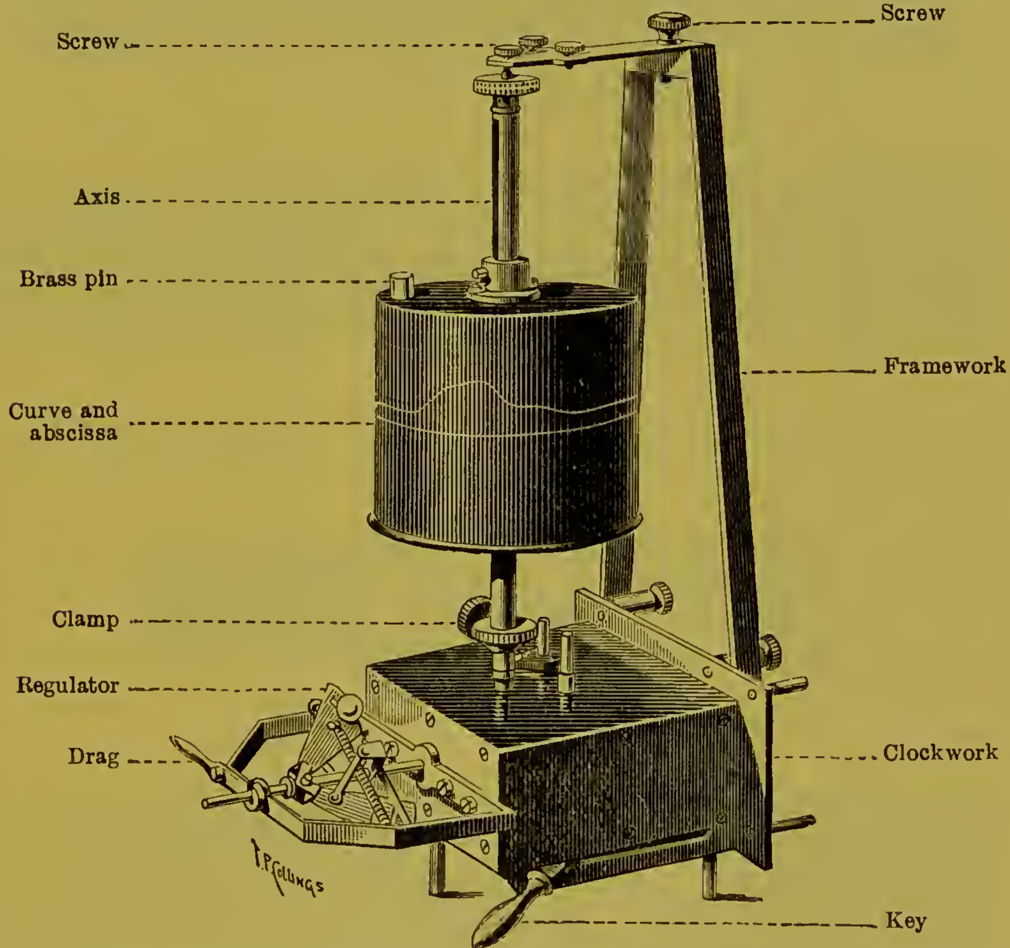


Fig. 53.—Revolving cylinder for recording movements. The screws at the top are for fixing the cylinder in position. The brass pin is for making or breaking a current at a given time in the revolution. It does this by striking against a small key. The curve is described by the levers, Figs. 20, 52, and 164. The abscissa, or zero line, is drawn by a fixed point, and serves to show the height of the contraction.

thickening. It is probable that both of these conditions occur, but for my own part I am inclined to believe that the arterial contraction plays a very great part in it, as we are able to reduce the tension by means of appropriate medicines, such as nitrites, which one would hardly do if it were entirely or even mainly due to a fibroid condition.

Effect of Heat and Cold on the Circulation.—Two agents which have a very marked effect, both upon the vessels and

FIG. 54.—Tracing of the normal contraction of the gastrocnemius of a frog.

a *b*

FIG. 55.—Effect of heat and cold on muscle. In *a* the muscle has been artificially warmed, and in *b* it has been cooled. Heat makes the contraction more rapid, cold makes it slower.

FIG. 56.—Effect of fatigue on muscle.

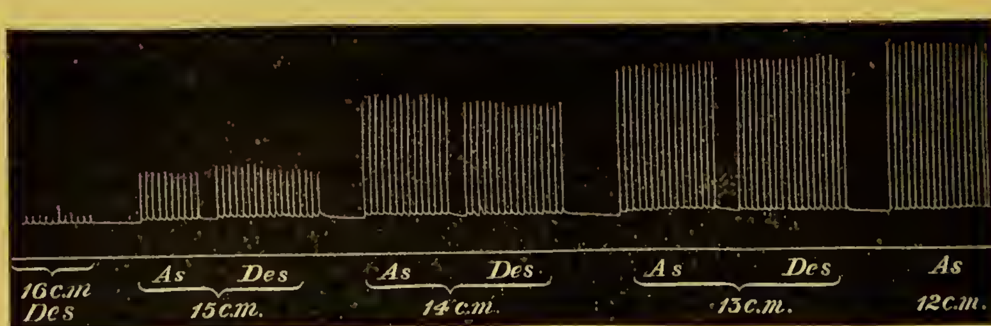


FIG. 57.—Tracing of the contractions of a muscle with stimuli of increasing strength. The numbers indicate the distance in centimetres of the secondary from the primary coil in the induction apparatus. *As* and *Des* indicate the ascending and descending direction of the current. *Cf.* Figs. 32 and 33.

the heart, as well as on muscular tissue generally, are heat and cold. When we put the hand into hot water we find at once

that the arteries dilate and the hand becomes red, showing that the capillary circulation is free; but we notice also that the veins not only become full, but become lighter in colour, evidencing that the blood within them is more arterial. Heat applied to the heart quickens its pulsations[1] and at the same time increases their strength, the quickening being chiefly due to the effect of the heat upon the sinus or auricles, and the increased strength to its effect upon the ventricle. (Fig. 59.) Cold has an opposite effect. (Fig. 64.) When applied to the extremities, it makes the arteries contract, the fingers shrink and become pale, though after a while the veins appear to dilate, and the skin assumes a bluish colour from venous congestion. Cold applied to the heart makes its movements both slower and feebler.

It is evident from what I have said that the local action of either heat or cold upon the vessels and heart is of such a character as in itself to co-ordinate the effect it produces upon both, independently of a nervous system, if applied to both at the same time; because when heat causes the vessels to dilate, so that a larger supply of blood is demanded, it also causes the heart to pulsate more quickly and more forcibly, so as to give the necessary supply. When the arteries are contracted by cold and a small amount of blood only can pass through them, the cold acts on the heart also, slowing and weakening its contraction and thus lessening the supply. But while cold and heat may act nearly equally upon the extremities and the heart of a frog, it is not so in warm-blooded animals, where the temperature of the interior of the body remains nearly the same, notwithstanding the extremes of heat and cold to which the extremities may be subjected, and in them it is necessary to have a nervous system to regulate the pressure of blood.

Effect of Heat and Cold on Pulmonary Capillaries. — By means of the apparatus shown in Fig. 68, I found that if a stream of warm moist air be first directed in the lung of a frog, and immediately afterwards a stream of cold moist air, the capillaries sometimes contract as much as one-third of their

[1] Lauder Brunton, *St Bartholomew's Hospital Reports*, 1871, vol. vii.; and, *Collected Papers* (First Series, p. 204).

FIGS. 58 TO 67.—EFFECT OF COLD AND HEAT ON THE HEART.

FIG. 58.—Tracing of the beats of a frog's heart, just after excision, made by the author with a simple lever (Fig. 20) and recording cylinder (Fig. 53). The beats are abnormally slow, probably from irritation of the vagus or venous sinus during excision.

FIG. 59.—Tracing from the same heart, in which the beats have been quickened by heat applied by placing a spirit lamp a good way under the plate on which the heart rests.

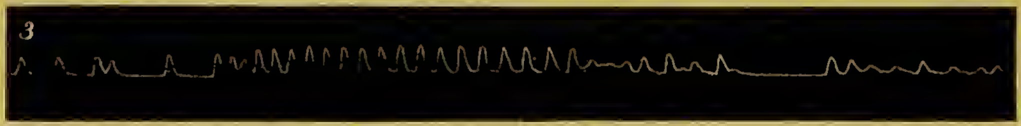


FIG. 60.—Continuation of Fig. 59. The heart is becoming warmer, and the beats become quicker, irregular, and intermittent.

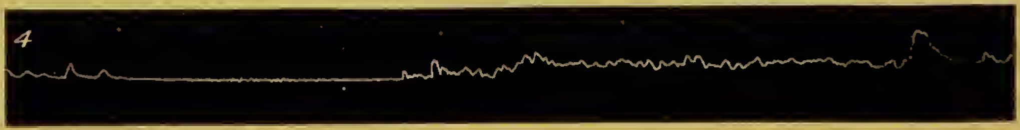


FIG. 61.—Continuation of Fig. 60. The heat has become greater, and the heart stops in heat tetanus. On the removal of the spirit lamp the beats recommence, but are faint and irregular.

FIG. 62.—Subsequent extreme slowing by placing a piece of ice under the plate on which the heart rested. The tremors are probably entirely due to the movement of the hand holding the ice, and not to the heart.

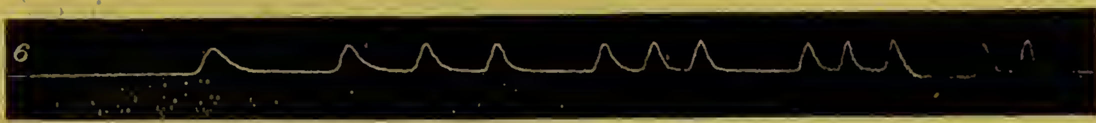


FIG. 63.—Shows the spontaneous recovery after removal of the ice. The beats occur in groups of three.

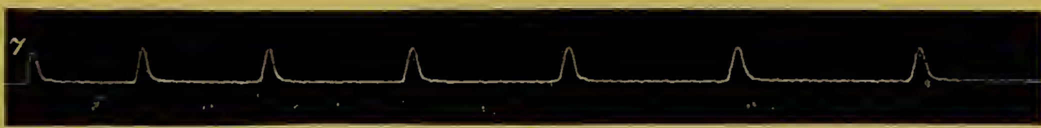


FIG. 64.—Cold was reapplied, and the beats again became slow.

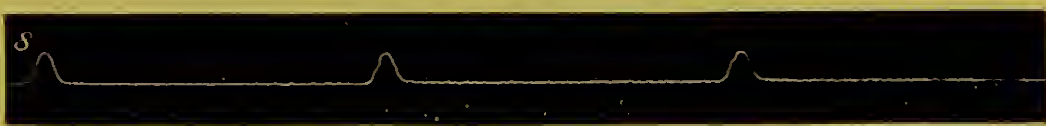


FIG. 65.—Continuation of Fig. 64. Increasing slowness of the beats as the heart becomes colder.

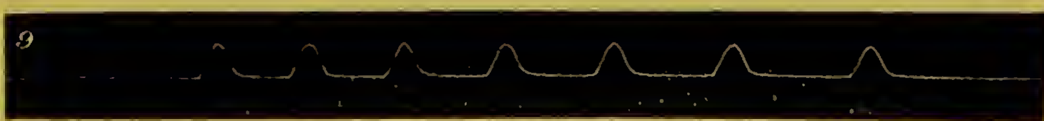


FIG. 66.—The first part of the tracing shows normal beats, the heart having recovered from the effects of the cold. The second part shows the effect of renewed heating. The slowness is probably due to the rapid change of temperature having irritated the vagus ends or inhibitory apparatus in the heart.

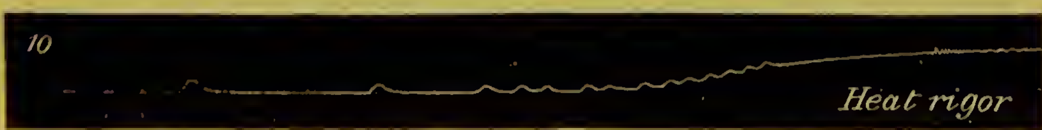


FIG. 67.—Continuation of Fig. 66. Shows increased slowness, then great rapidity, and final stoppage in heat rigor.

diameter under the influence of the cold.—*British Medical Journal*, February 13, 1875.

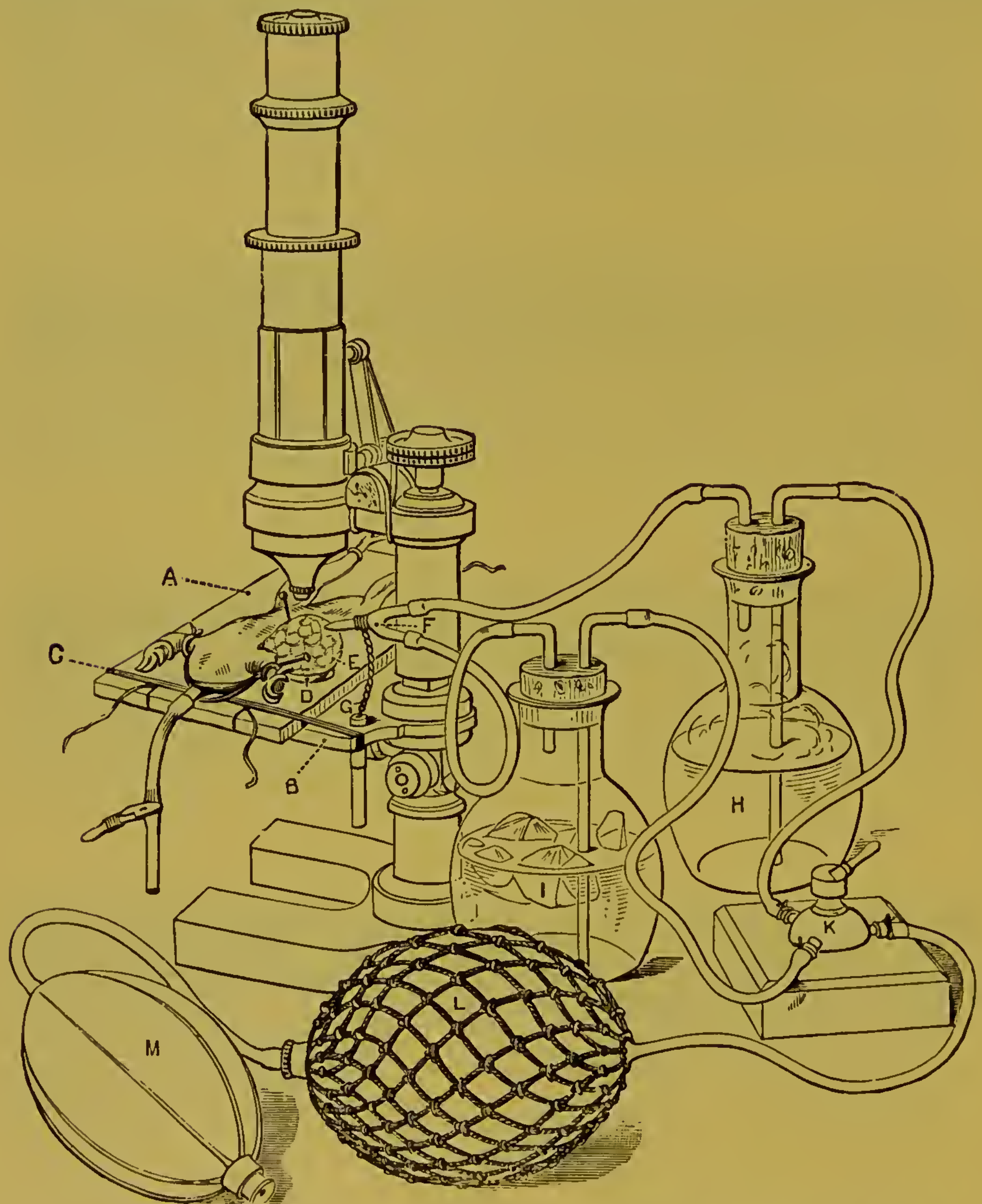


FIG. 68.—Author's apparatus for ascertaining the effect of heat and cold on the vessels of the frog's lungs. A, a piece of cork to which the frog is fastened, is laid on B, the stage of a microscope, and attached by an india-rubber strap, C. D is a small ring of cork covered with a thin circle of glass. E is the inflated frog's lung. F is a tube by which a current of air can be directed on the frog's lung. It is held in position by a piece of wire, G, which can be bent to any position. I is a flask containing ice and water. H, a flask containing hot water. K is a three-way stopcock, by which a current of air may be sent from the spray-producer, L and M, through either I or H at will, and thus cold or hot air may be applied alternately to the lung.

Schema of the Circulation.—I have here a simple schema,

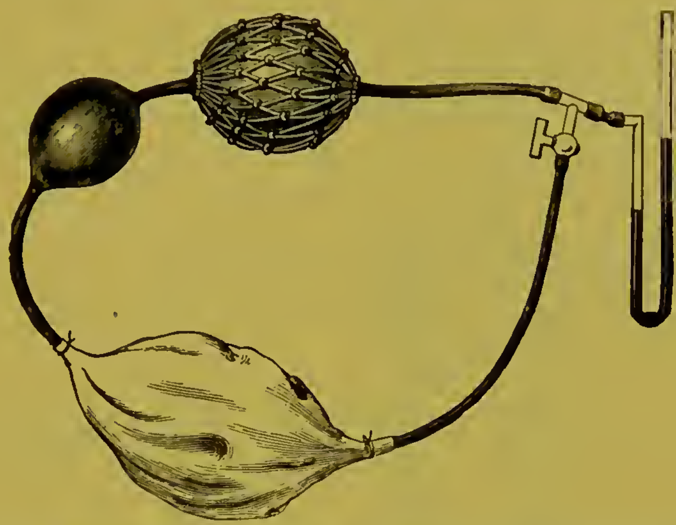


FIG. 69.—Author's schema of the circulation. It consists of a spray producer, bladder, and mercurial manometer. The elastic ball of the spray producer represents the heart, the elastic bag covered with netting to prevent too great distension represents the aorta and arterial system, and the bladder represents the venous system.

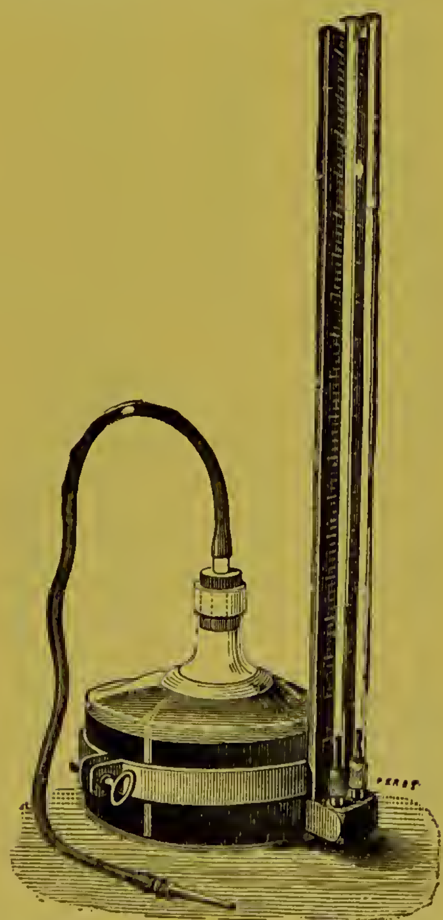


FIG. 70.—Marey's hæmodynamometer. By having the reservoir of mercury very large, the descent of mercury in it is practically negligible, and the pressure may be read off directly from the ascending limb. Two tubes are attached. In one the mercury oscillates rapidly, with variations in pressure. In the other there is a constriction, the mercury hardly oscillates at all, and the mean pressure is thus easily ascertained.

consisting of an india-rubber ball representing a heart, an elastic bulb representing the arteries, a soft-walled bag representing the veins, and this I have connected with

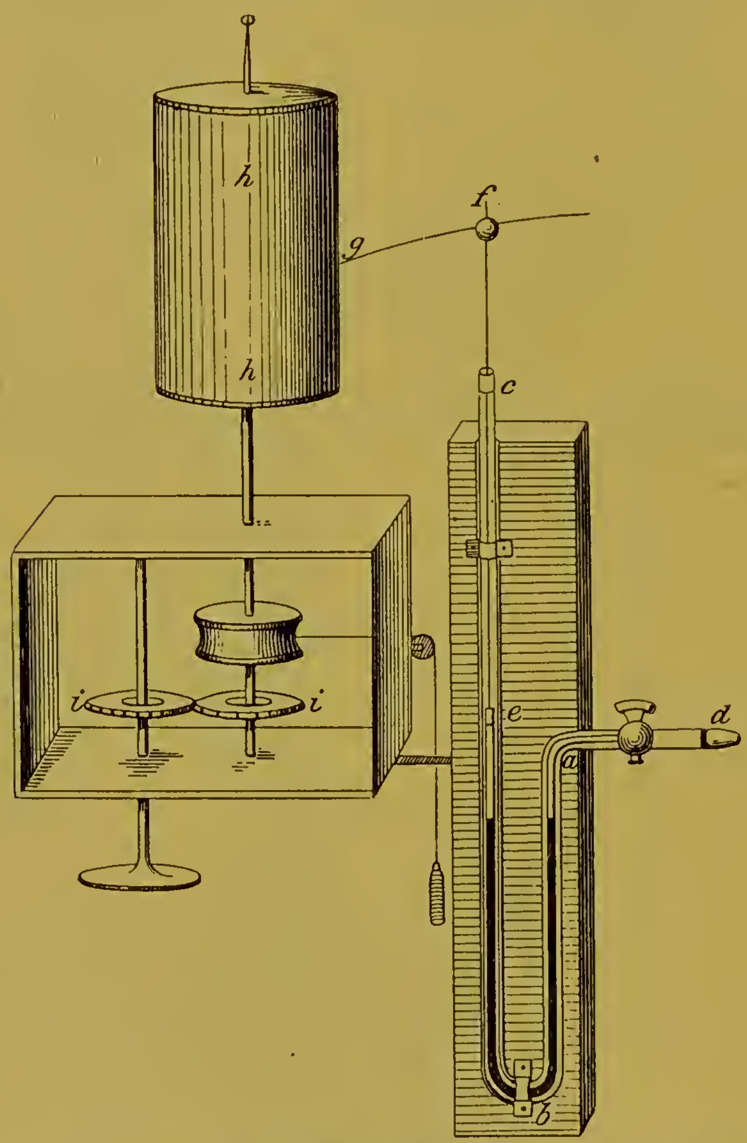


FIG. 71.—Ludwig's kymograph, copied from *Ludwig's Lehrbuch der Physiologie*, 2te Auflage, 2ter Band, p. 122. It consists of a bent glass tube, *a b c*, containing mercury, and connected by *d* with the artery of an animal. *e f* is a slender upright rod, swimming on the surface of the mercury, and bearing at its free end, *f*, a brush, *g*, which registers the movements of the mercury on the revolving cylinder, *h h*.

a mercurial manometer, in order that you may see the comparative effects of the heart and vessels upon the pressure in the arterial system. (Fig. 69.) The soft-walled bag, or veins, can contain all the fluid in the whole vascular system, or even

more, so that we may commence with the pressure at zero. As the india-rubber ball, which I may shortly call the heart, is emptied, it drives the fluid into the elastic bulb, or arterial system. If the passage is left open into the venous bag, the mercurial column oscillates with each pulse, rising as the fluid is driven in, and sinking again in the interval. But if I slightly turn the stopcock so as to prevent all the fluid driven in at

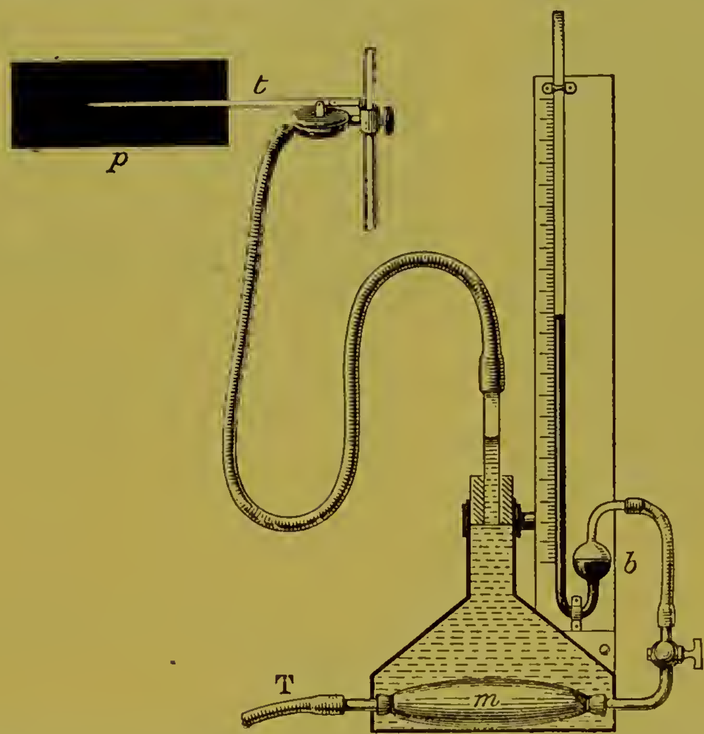


FIG. 72.—Registering metallic manometer of Marey. *m* is the capsule of an aneroid barometer filled with liquid. T is a tube connecting *m* with an artery. *b* is a mercurial manometer, which can either be put in communication with *m*, and the exact pressure in it and the artery connected with it ascertained, or may be cut off by the stopcock. *t* is a registering apparatus, and *p* a blackened plate on which the lever writes. When the stopcock is open the lever will record the oscillations caused by the momentum of the mercury, but if it be shut as soon as the actual pressure has been ascertained, only the actual variations in the blood pressure will be recorded.

each pulsation from going into the veins, the pressure will gradually rise in the bulb until it is sufficient to drive out during the diastole all the fluid sent in during the systole.

Kymographs.—The pressure is measured in animals by putting a cannula into an artery and connecting it with a mercurial manometer. In order to prevent coagulation, the tube leading from the artery to the manometer is filled either with some saline solution, or solution of peptone, which hinders coagulation. The oscillations of the mercurial column are

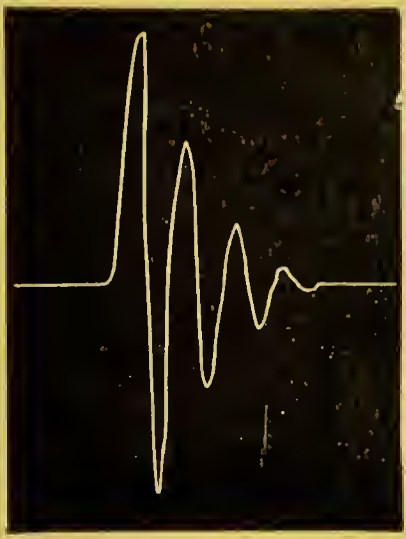


FIG. 73.—Tracing of the oscillations in a mercurial manometer. The first upward stroke is due to sudden rise of pressure. The subsequent fall below zero and the other oscillations are due to the inertia of the mercury, and not to any external force. *Cf.* Fig. 74. The oscillations are less when the manometer is connected with an artery. (Figs. 183 and 185.)

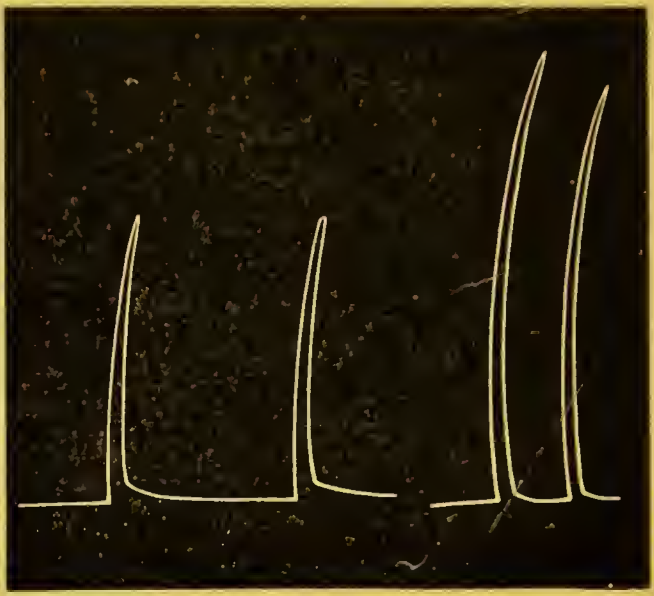


FIG. 74.—Tracing made with one of Marey's tambours. The upward strokes correspond to rise of pressure in the tambour. The inertia of the lever is very small, and consequently there are no secondary falls below the zero line, nor secondary oscillations, as in a mercurial manometer. *Cf.* Fig. 73.

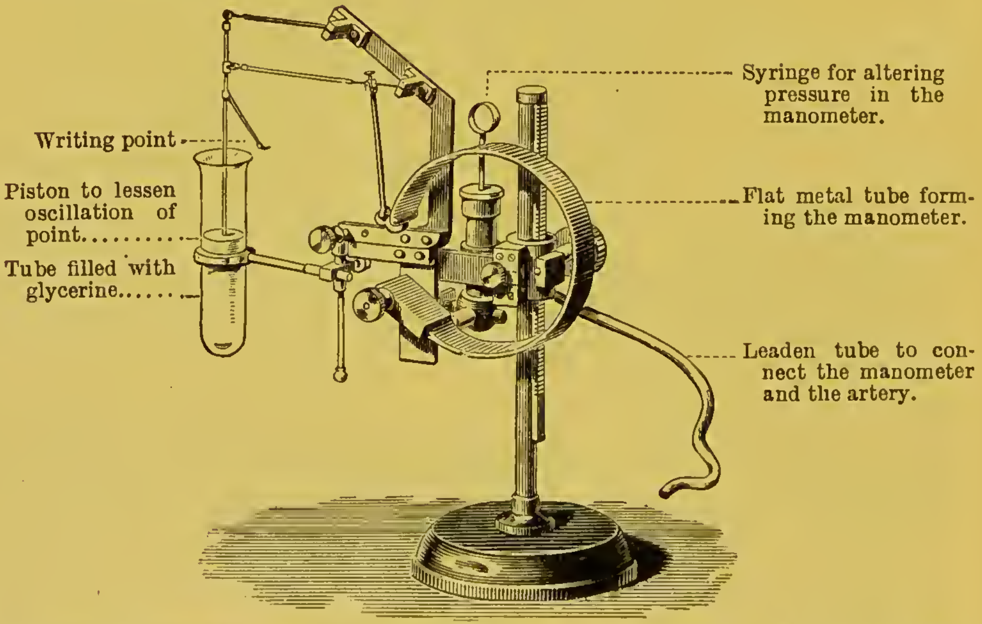


FIG. 75.—Fick's kymograph. It consists of a flat metal tube, bent into a nearly circular form, filled with alcohol, and connected with the artery by means of a leaden tube, filled with a solution of sodium carbonate. When the pressure increases within it, the tube straightens, and when the pressure diminishes it bends. These changes are magnified, and recorded on a cylinder by a light lever. The vibrations of the lever are lessened by a piston, which works in a tube filled with glycerine.

recorded on a revolving cylinder, and the whole instrument, consisting of mercurial manometer and recording cylinder, is called a kymograph.

You will notice that when the mercury is once set into oscillation it continues to oscillate for a length of time after the force which first started it has ceased, and in this way prevents us from getting any exact information regarding the time during which the force has acted. (Fig. 73.)

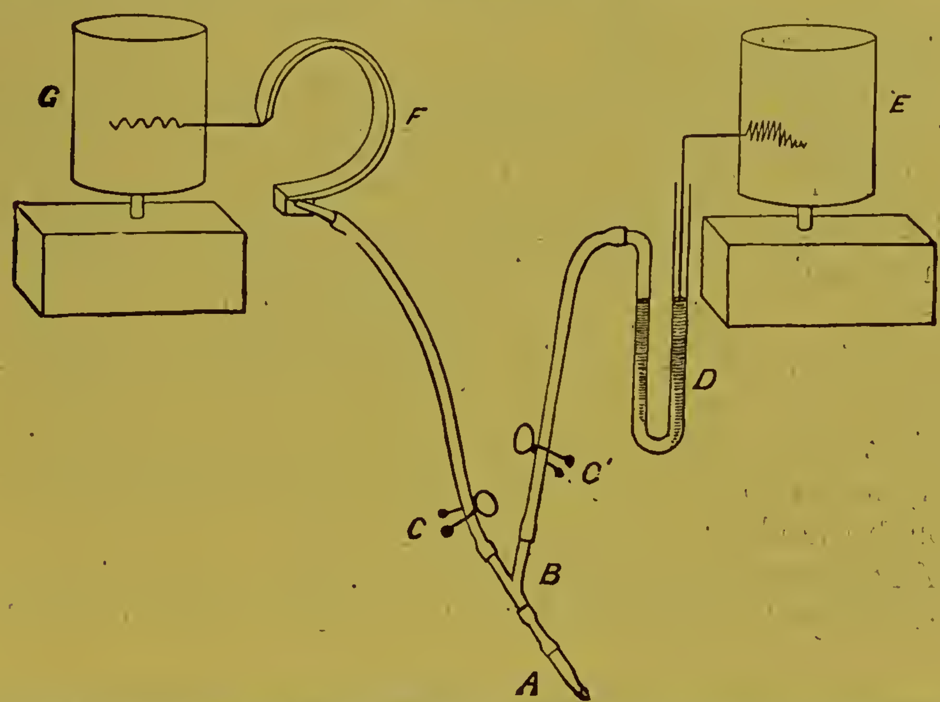


FIG. 76.—Diagram to illustrate author's method of combining Ludwig's and Fick's kymographs for registering the blood pressure and pulse. A is the cannula for insertion into an artery. B is a Y-tube by which the artery can be put in communication either with a mercurial manometer D, or a Fick's kymograph F, or with both of them at the same time. C and C′ are two clips by which the communication of either or of both manometers with the artery can be shut off at will, or a three-way stopcock may be employed instead. E is a slowly revolving cylinder on which the mercurial manometer registers the blood pressure. G is a rapidly revolving cylinder on which the Fick's kymograph registers the pulse beats from time to time, and on which the respiration can also be registered. (*Phil. Trans.*, 1891, vol. clxxxii.)

In order to avoid these intrinsic oscillations other recording instruments have been employed, such as the spring manometer of Fick, in which the tension causes a curved tube to straighten or bend (Figs. 75 and 76), or the manometers of Hürtle or Roy, where the oscillations are very small, but are much magnified by the recording lever.

Blood Pressure in Animals.—The average blood pressure in animals varies according to their size, but not to the extent

that we should imagine. In a horse it has been found to be roughly between 200 and 300 millimetres, in a dog 140 to 170, in a sheep 150 to 170.

Blood Pressure in Man.—In man it has been found to be from 100 to 160,[1] in cases where it was estimated in a limb before amputation.

Measurement of the Blood Pressure in Man.—It is naturally of very great importance that we should be able to estimate the pressure in man, and numerous instruments have been devised for this purpose.

By simply feeling the pulse with a finger, one can roughly make out whether the pressure within it is high or low, and this is still better done by placing three fingers upon the pulse and compressing it with the one nearest the heart and noticing with the middle one when it ceases to beat. By the amount of pressure exercised, one can form some judgment regarding the tension, but it is evident that one cannot convey any quantitative knowledge regarding the pulse felt this way to another. The third finger nearest the hand compresses the artery so as to obstruct the recurrent pulse from blood flowing through the ulnar artery and palmar arch.

Instruments for Measuring the Blood Pressure in Man.—These may be roughly divided into two classes: (1) those

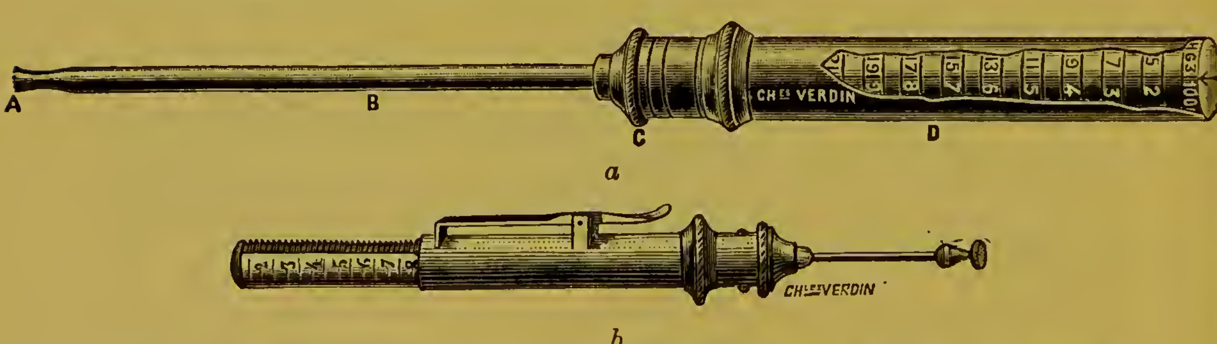


FIG. 77.—*a*, Simple instrument for measuring the blood pressure in an artery. *b*, In this an improvement has been made on the simpler form by adding a side spring catch, which obviates the necessity of reading the index before removing it from the arm.

which compress a single artery; (2) those which compress a digit or limb. One instrument of the first class is simply a

[1] Faivre and Albert, quoted by Tigerstedt, *Lehrb. d. Physiol. d. Kreislaufs*, p. 329 (Leipzig: Veit & Co., 1893).

little knob attached to a graduated scale in a spring balance, like what is often used for weighing letters. (Figs. 77 and 78.)

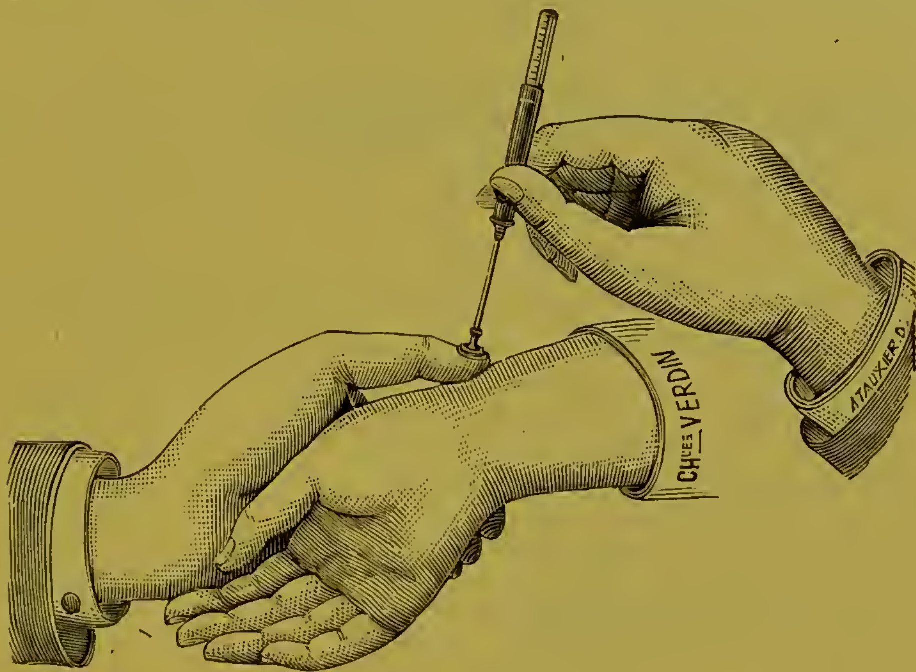


FIG. 78.—Shows the mode of applying the simple sphygmomanometer, by pressing it directly on the palpating finger instead of pressing it on the artery, and feeling the artery nearer the hand. (After Verdin.)

The movement of the scale here is so small that it is practically of little use. In another more elaborate one the movement is

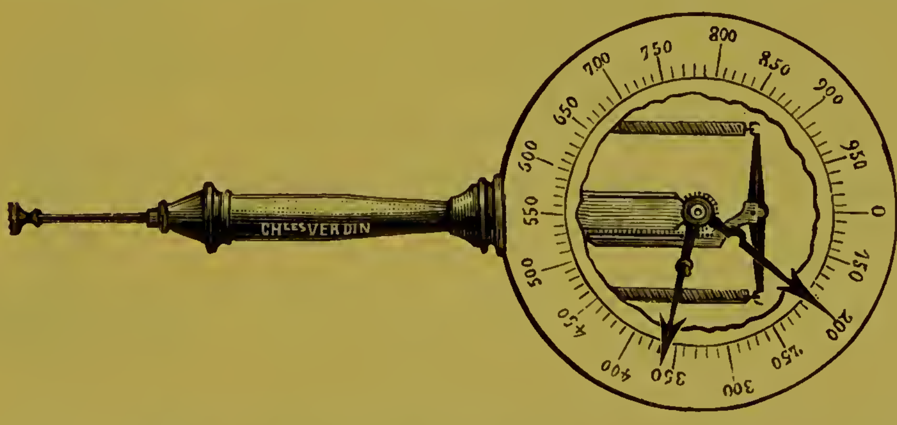


FIG. 79.—Shows an instrument in which the movements of the spring are magnified and read off on a dial. There is a movable index which is pushed on by the indicator, and left at the maximum point. (After Verdin.)

multiplied by a wheel, so that the pointer shows the pressure on a large dial (Fig. 79), but this instrument also is unsatis-

factory, as it is difficult to apply it directly over the vessel, and the data obtained from it are not very trustworthy. Better and more exact results are obtained by the substitution of a fluid for

FIG. 80.—Instrument for estimating the pressure of blood in the capillaries.

a solid pad. So far as I know, the first man to use a fluid pad over the artery was Hérisson. His instrument consisted of a small funnel covered at its larger end by a thin membrane, and having a long graduated glass stem at its other end. (Fig. 81.) The whole apparatus was filled with mercury. The simple apparatus of this sort which I now show you was made by Professor Waller. When it is placed upon the radial artery you see the mercury oscillating with each beat, and by and by when the pressure applied to the vessel becomes sufficiently great the pulsations below the instrument cease.

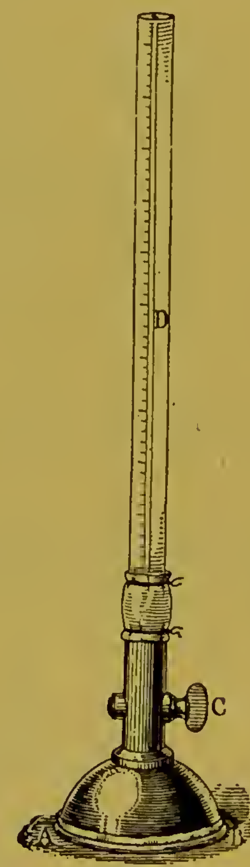


FIG. 81. — Sphygmomanometer of Hérisson. (After Marey.)

The disadvantage of Hérisson's instrument and others made upon the same pattern is, that it is very difficult to keep the mercury from oozing out between the end of the funnel and the membrane which covers it. To obviate this difficulty, my old friend Von Basch enclosed the mercury in a glass bulb into which the glass tube passed. This was then enclosed in an outer cylinder the lower end of which was covered by membrane, and which was filled with water, which transmitted the pressure to the mercury through a small hole in the bulb. This manometer was screwed into a stand in which the wrist was clamped, and the manometer gently depressed on the radial until the pulsation ceased, as was indicated by a small pad resting on the artery

and communicating with a Marey's tambour. This was the first instrument of real practical use, and although Hérisson's instrument was long anterior, yet Von Basch must, I think, be regarded as the practical founder of the measurement of blood pressure in man. (Figs. 82 and 83.)

A good many years ago I got Mr Cetti, of Brook Street, Holborn, to make up instruments of this sort for me for use in

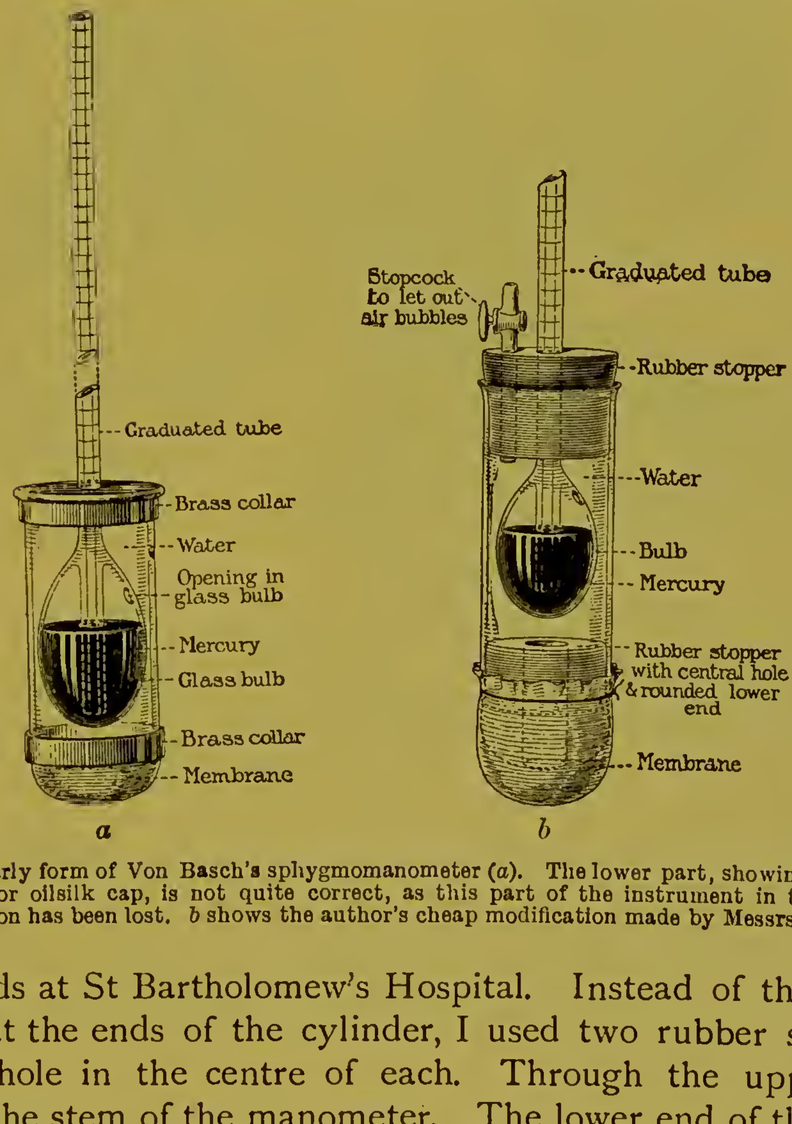


FIG. 82.—Early form of Von Basch's sphygmomanometer (*a*). The lower part, showing the india-rubber or oilsilk cap, is not quite correct, as this part of the instrument in the author's possession has been lost. *b* shows the author's cheap modification made by Messrs Cetti & Co.

the wards at St Bartholomew's Hospital. Instead of the metal collars at the ends of the cylinder, I used two rubber stoppers with a hole in the centre of each. Through the upper one passed the stem of the manometer. The lower end of the other stopper was rounded at the edges, so that the membrane fitted better over it, and it could be applied more easily to the artery. These instruments Mr Cetti manufactured for a few shillings. I found a small stopcock in the upper stopper useful for the

removal of air-bubbles, and complete filling of the cylinder with water. (Fig. 82 *b*.)

The instrument had the great disadvantage of not being portable. Unless it was kept upright and was not shaken, the

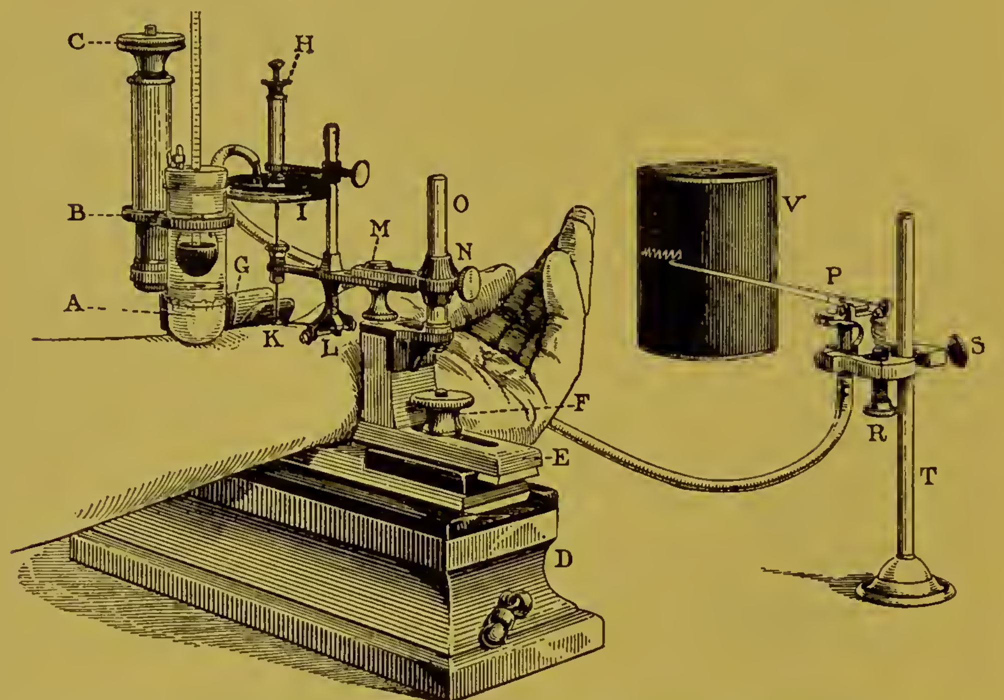


FIG. 83.—Von Basch's sphygmomanometer and stand. Drawn from one in the author's possession. A is the indiarubber cap of the sphygmomanometer resting on the radial artery. B is a metal ring which holds the sphygmomanometer, and can be raised or lowered at will by the screw C. D is the stand in which the arm rests. E is a sliding piece which holds the arm in position, and also supports the sphygmograph I. F is a screw to fix E in position. G is a fixed projection at the other end of D, and the wrist is clamped between E and G. G consists of two parts, one of which is quite fixed; the other, indicated by K, can be pressed more or less firmly against the arm by a fine screw not shown in the drawing. H is a fine screw by which the tambour of the sphygmograph can be raised or lowered so that it rests with more or less pressure on the top of the rod which passes up from a small pad which rests in the artery. K indicates the position of this pad as well as of the movable piece of G. L is a joint in which a lever plays, the outer end of which is fixed to the pad K, and keeps it moving in a perpendicular line. M is a joint allowing of considerable horizontal play backwards, forwards, laterally, and circularly, so that the sphygmograph may be accurately adjusted over the artery. N is a screw by which the whole sphygmograph may be moved up and down on the stand O. P is one of Marey's tambours, communicating by a piece of elastic tubing with the tambour of the sphygmograph, and writing the pulse on the blackened cylinder V. R is a screw working on a spring, by which the resistance of the lever resting on the tambour may be adjusted. S is a screw by which the tambour may be moved up and down on the stand T. V is a revolving cylinder covered with blackened paper, on which the tracing is taken. It is moved by clockwork, which is not shown in the drawing.

mercury and water became mixed, and the instrument was useless for the time. It was therefore of little value for clinical work. Von Basch accordingly invented another model, in which pressure was applied over the artery by a metal cap covered at one end by a thin membrane, and communicating

at the other by a thick-walled rubber tube with an aneroid barometer graduated in millimeters of mercury. In a later model the metal ring communicated with the aneroid by an opening in its side; one end was covered with thin india-rubber for application over the artery, and the other with thick india-rubber on which the finger was pressed until the pressure inside the apparatus was sufficient to stop the pulse. (Fig. 84.)

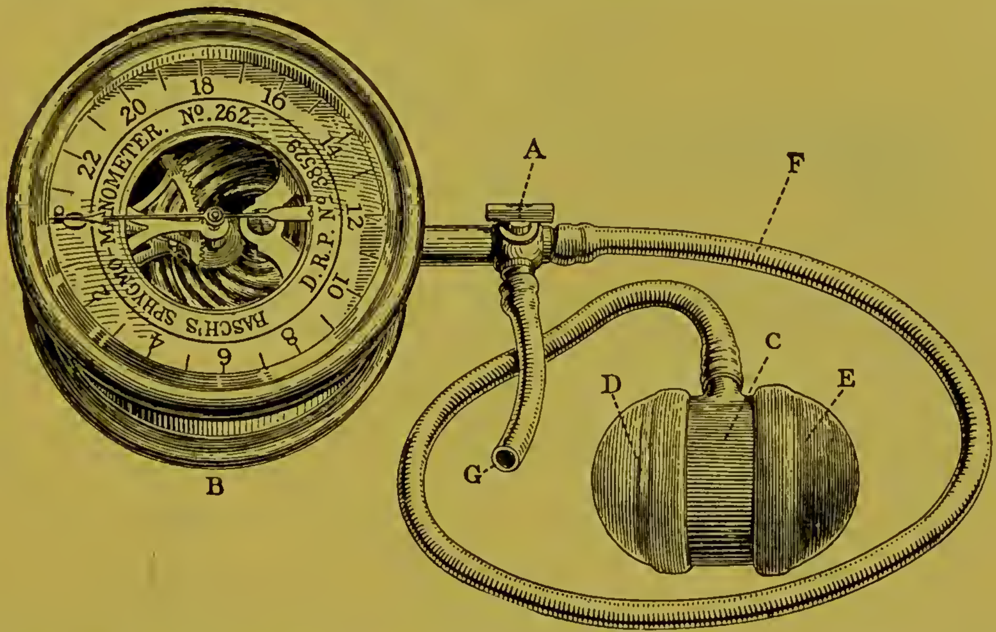


FIG. 84.—Von Basch's sphygmomanometer, from a specimen in the possession of the author. A is a three-way stopcock, by which the aneroid B can be put in communication either with the bulb C or with the outer air. This is not the first form of Von Basch's sphygmomanometer. The bulb which he first used was included in a metal case somewhat resembling Marey's cardiograph. My instrument needed repair, so I sent it to Vienna, and it was returned by the maker, with the bulb figured above.

A further improvement was introduced by Potain, who replaced the metal ring by moderately thick rubber, so that the bulb for application over the radial consists of thin rubber at the side which lies against the wrist, thick rubber (usually of a red colour) at the opposite side on which the compressing finger rests, and moderately thick rubber between. With this exception, Potain's instrument is the same as Von Basch's. (Fig. 85.)

The latest form of Von Basch's apparatus is still simpler, and consists of an elongated rubber bag of the same thickness in every part.[1] (Fig. 87.)

[1] This is made in Vienna, but can be obtained from Messrs Down Bros., 21 St Thomas's Street, S.W.

Fig. 85.—Potain's modification of Von Basch's sphygmomanometer. This is made by M. Boulitte, successor to M. Charles Verdin, 7 Rue Linné, Paris.

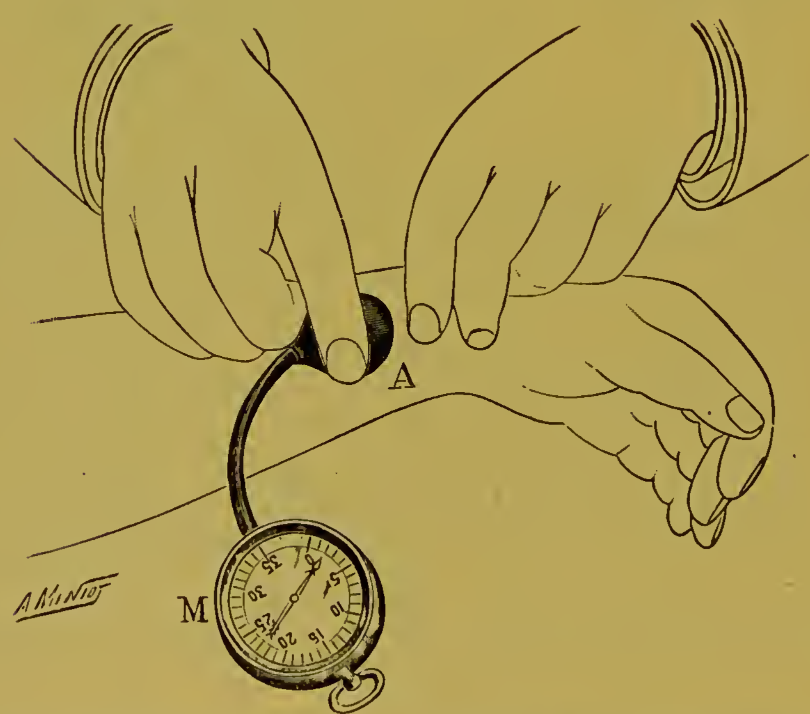


Fig. 86.—Mode of applying Potain's sphygmomanometer. This figure is not quite correct, for it is better to place the palpitating finger parallel to the artery instead of at right angles to it. Only one finger should be used to feel the pulse, as, if two are used, the elastic bulb is pushed too high above the end of the radius, and too high a reading is obtained.

Fallacies in applying Von Basch's or Potain's Instruments.—Unless the elastic bulb is placed above the end of the radius, and not over the soft tissues, so that the artery can be compressed between it and the bone, too high a reading is obtained. If the palmar arch is dilated the recurrent pulse through it from the ulnar artery may cause pulsation to be felt after the radial has been completely compressed by the bulb. To avoid this the palpating finger should be placed on the radial artery with the tip pointing upwards. Any recurrent pulse is then stopped by the pulp of the finger, and the central radial pulse is felt by the finger tip.

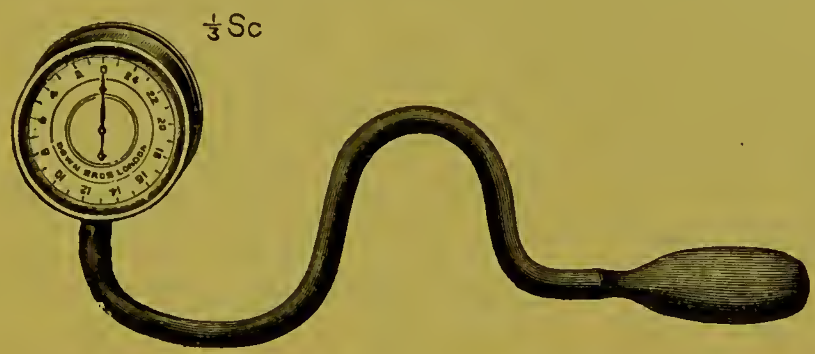


FIG. 87.—Most recent form of Von Basch's sphygmomanometer.

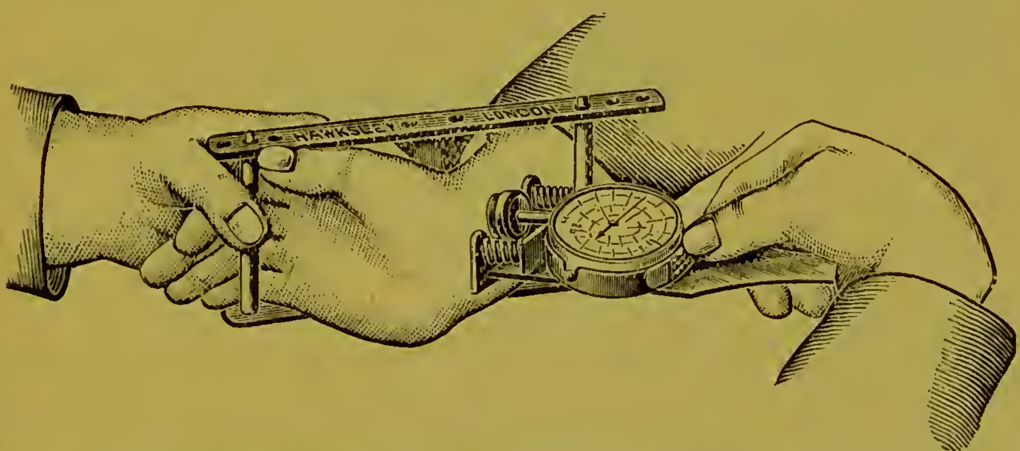


FIG. 88.—Oliver's Sphygmomanometer. Instead of the pad which rests on the artery being solid, it consists of an elastic capsule containing fluid. This is made by Mr Hawksley, 357 Oxford Street, London.

Another apparatus which also depends on the application of

a fluid bulb over the pulse, is a very neat little one invented by Mr Leonard Hill. Like Hérisson's, it consists of a funnel closed at one end by a thin membrane. The funnel is very flat, and Mr Hill has avoided the difficulty of using mercury, and has rendered the instrument portable by employing a coloured liquid having no weight in itself, but working against the resistance of a column of air prevented from escaping by a stop-cock at the upper end of the tube, and compressed by any pressure on the membrane. It is very light and portable, but unless a good deal of care is taken, air-bubbles are apt to become mixed with the liquid, and cause some loss of time before they

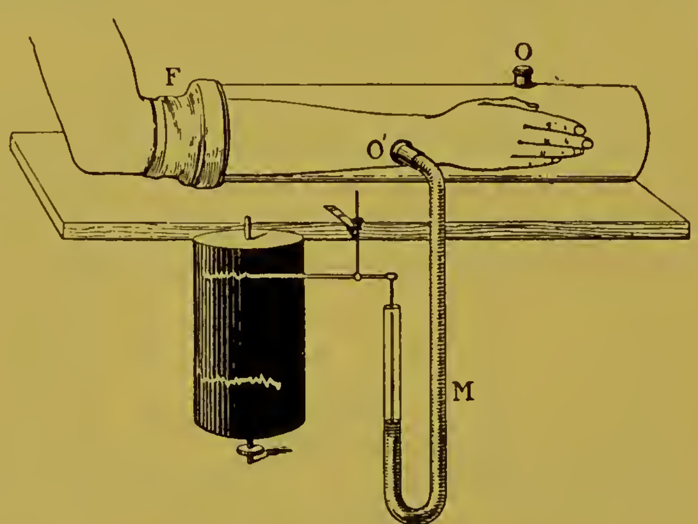


FIG. 89.—Fick's apparatus for measuring and recording changes in the volume of organs. (After Marey.)

can be got rid of. Oliver's hæmodynamometer has, like those just described, a fluid pad consisting of thin rubber filled with water and glycerine, for application over the artery. The pressure from this pad is not conveyed from its interior to a recording apparatus, but by a rod, one end of which rests upon it whilst the other presses in a spring. The motion of the spring is shown, greatly magnified, by an index, which moves over a scale 11 inches long, but conveniently arranged in the form of a helix on a dial 2 inches in diameter. (Fig. 88.)

Band Instruments for estimating Blood Pressure. — Instruments belonging to the second class, viz., encircling a digit or a

limb, were first used by Piégu, Chelius, Fick, Buisson, Marey, Mosso, and François, to measure the volume of blood which enters a limb at each pulse, and show the kind of pulsation in them under various conditions of the circulation, rather than to measure the pressure of blood in the arteries. Piégu enclosed

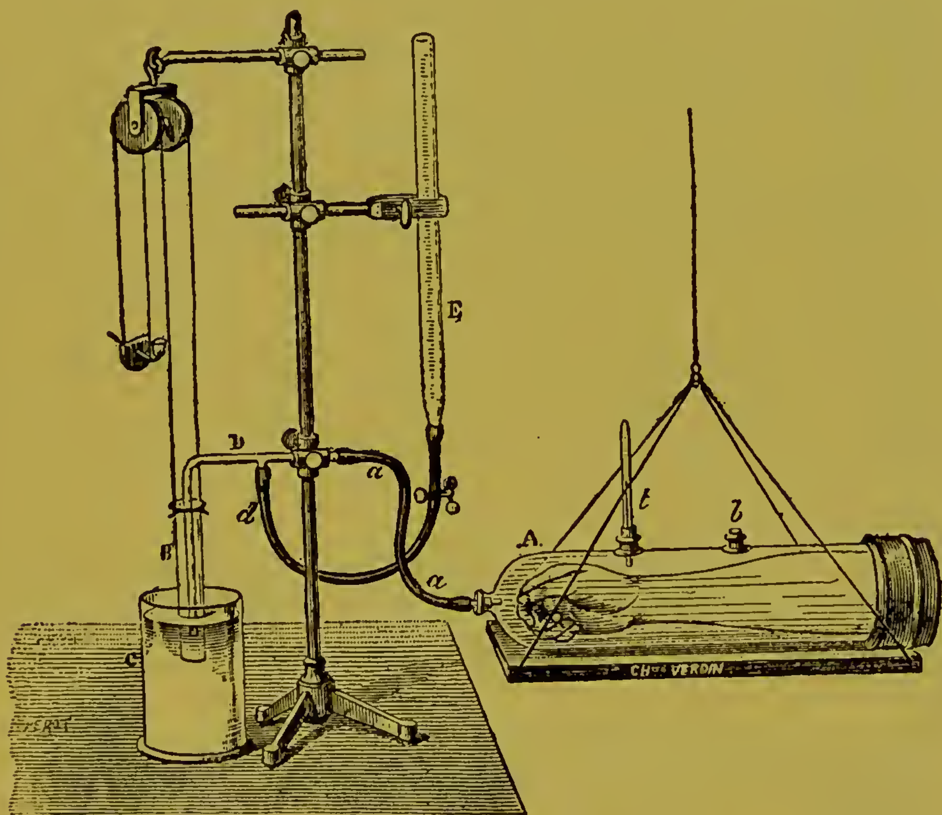


FIG. 90.—Mosso's plethysmograph. A is a glass vessel filled with oil or water in which the arm is inserted and the liquid prevented from escaping by an india-rubber cap. *t* is a thermometer, *b* an opening for filling or emptying the apparatus. When the arm swells, a little of the fluid passes from the glass vessel through the tube *a* into the test-tube B, which is thus rendered heavier, and by a thread running over a pulley raises the writing point and registers the increased size of the arm. When the vessels of the arm contract, its size diminishes, fluid returns into A and the writing point falls. *c* is a vessel containing water, in which the tube B is partially immersed so that its weight is counterbalanced. E is a burette which can be made to communicate or clamped off at will, and the quantity of fluid in B regulated to a nicety.

an entire limb in a vessel filled with tepid water, and furnished with a narrow tube in which the water could be seen to rise and fall with each pulsation. Chelius and Fick independently connected this tube with Ludwig's kymograph, and were thus able to obtain tracings of the variations. The apparatus was perfected by A. Mosso, who gave it the name of plethysmograph.

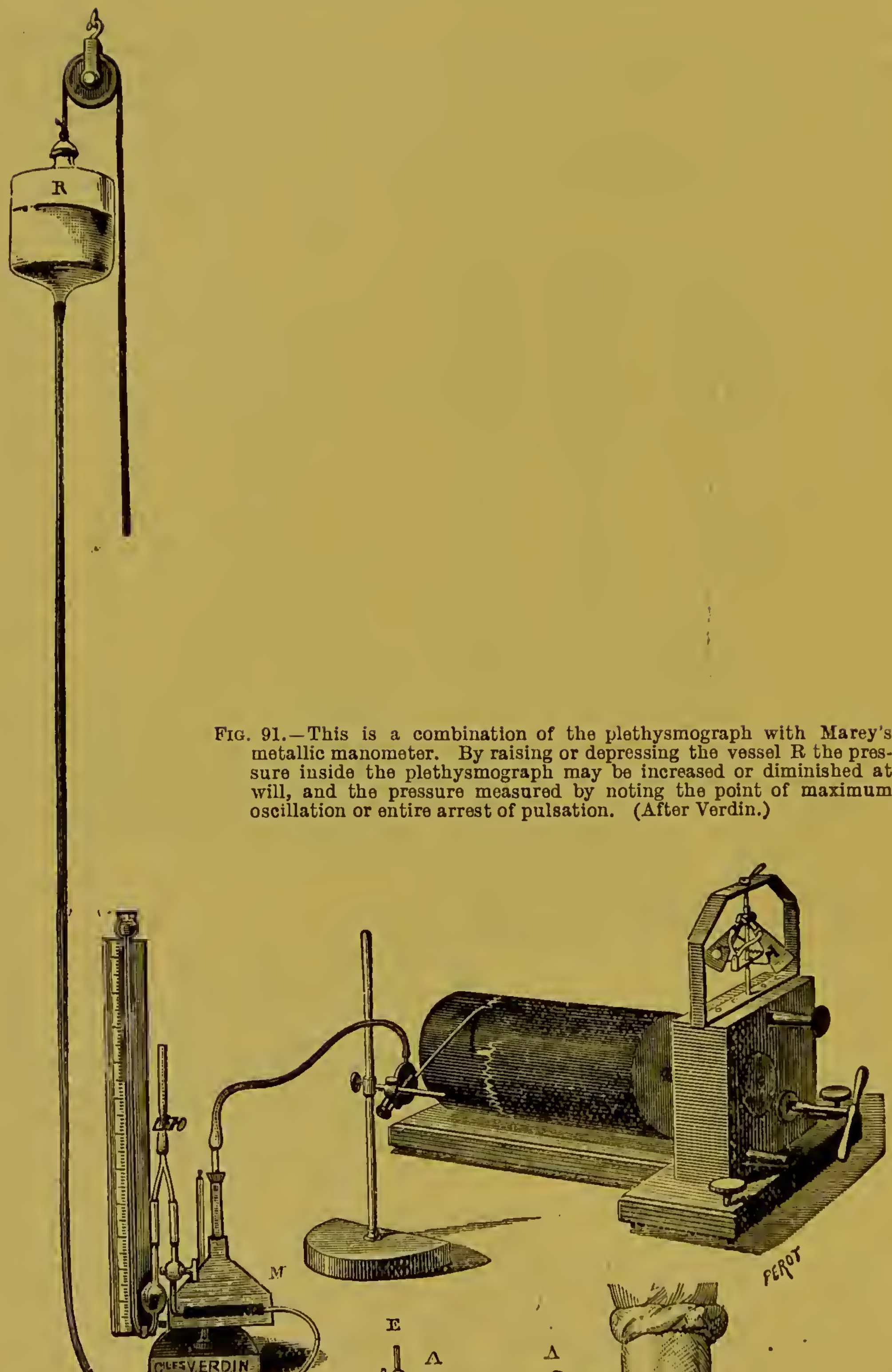


FIG. 91.—This is a combination of the plethysmograph with Marey's metallic manometer. By raising or depressing the vessel R the pressure inside the plethysmograph may be increased or diminished at will, and the pressure measured by noting the point of maximum oscillation or entire arrest of pulsation. (After Verdin.)

When the pressure in such an instrument is artificially raised the oscillations increase up to a certain maximum, then diminish, and finally cease. The maximum is considered to represent the diastolic pressure in the arteries, and the cessation to be equal to the systolic pressure. It is not easy to prevent leakage when the pressure is raised in an instrument where the limb is immersed directly in the fluid, for it is apt to exude between the skin and the rubber collar surrounding the limb, unless the ligature is so tight as both to be very uncomfortable to the subject and to interfere with the circulation.

Marey[1] and Mosso both overcame this difficulty, by enclosing liquid by a thin membrane through which the pulsations of

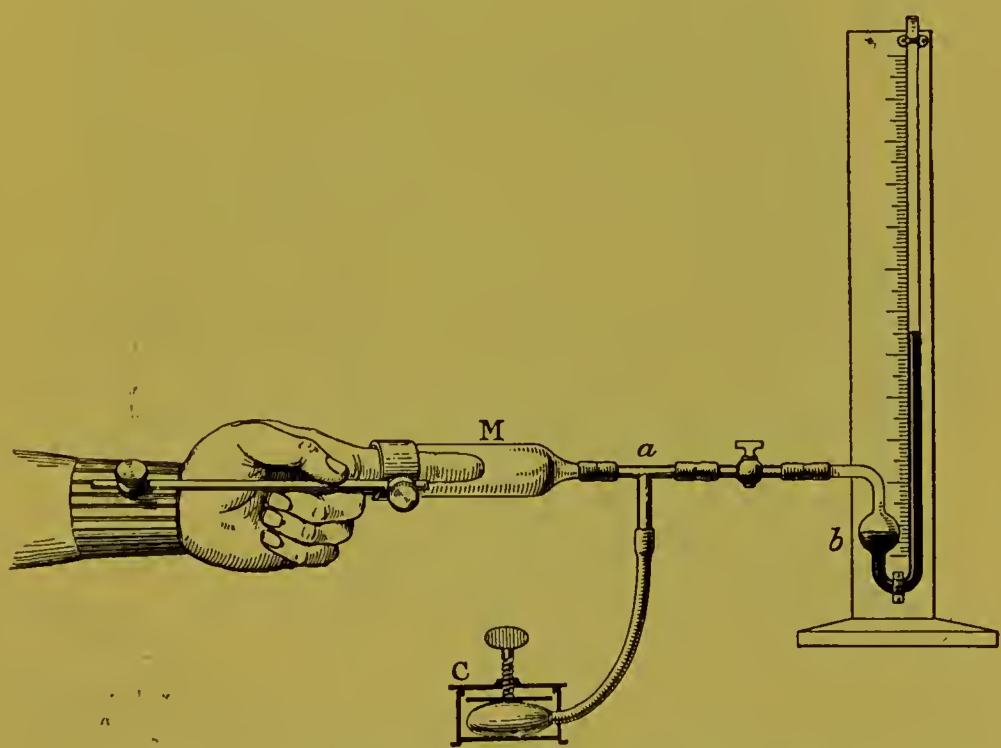


FIG. 92.—Marey's apparatus for measuring the blood pressure in a finger.

the finger or limb were transmitted. In Marey's instrument only one finger was enclosed, while in Mosso's four fingers are introduced into the sphygmomanometer. In both of these instruments the pressure is raised artificially by driving in air or

[1] Marey, *Trav. Lab.*, tom. ii., p. 313.

water, until the oscillations of the manometer reach a maximum, and then pushing the pressure till they cease altogether, and the circulation in the fingers is stopped. By relaxing the

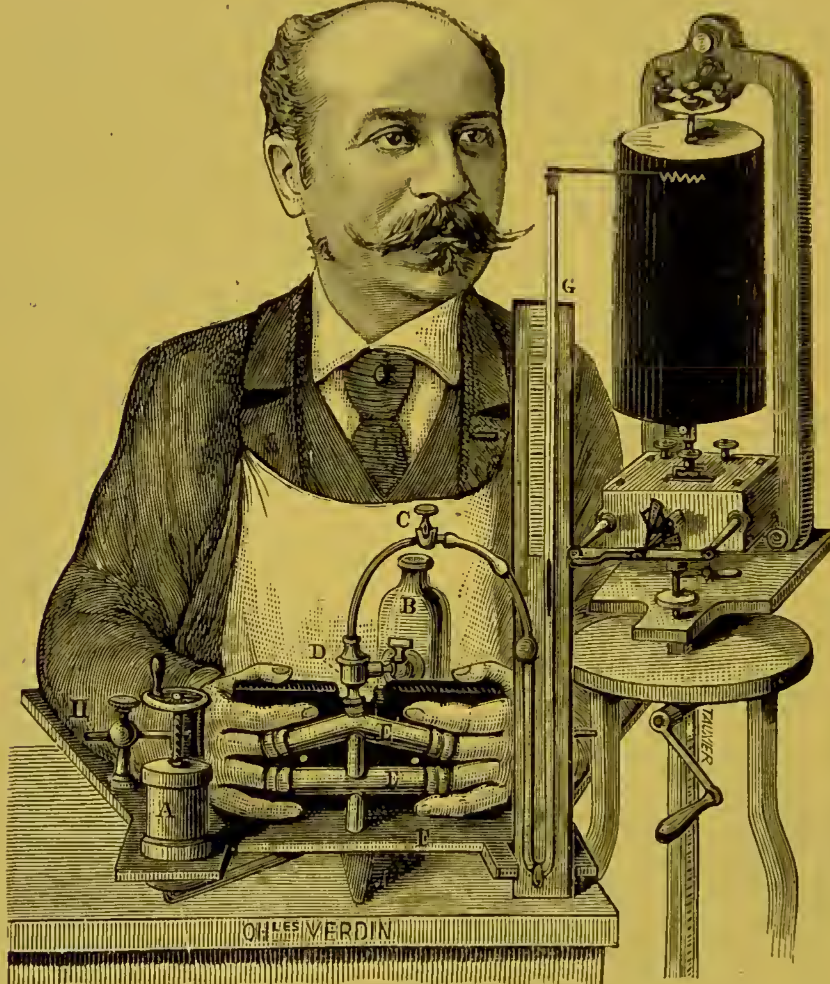


FIG. 93.—Mosso's sphygmomanometer. It consists of metal tubes (E E) filled with water, which is prevented from coming out by india-rubber finger-stalls into which the fingers are inserted. The apparatus is then quite filled with water from the bottle B, air being allowed to escape at C. The pressure is then raised by compressing the water in the reservoir (A) by the screw at its top until the mercury in the manometer (G) registers the maximum oscillation, which may be taken as the diastolic pressure. The pressure is then raised until the mercury ceases to oscillate, and this may be taken as the systolic pressure.

pressure the oscillations again reach a maximum as the circulation again returns. In this way, a double observation is made.

In Gaertner's tonometer the pressure is measured by empty-

ing a finger of blood, and noting under what pressure the circulation returns. (Fig. 95.)

It consists of a metal ring 1.5 cm. broad, to the inside of which an india-rubber membrane is fixed, so as to leave an air space between it and the ring. (A, Fig. 97.) This space communicates by an opening in the side of the ring, and a **T**-tube with a mercurial manometer and a pressure ball consisting of a closed india-rubber bag compressed in a wooden vice. An open bag with good valves and adjustable outlet may be

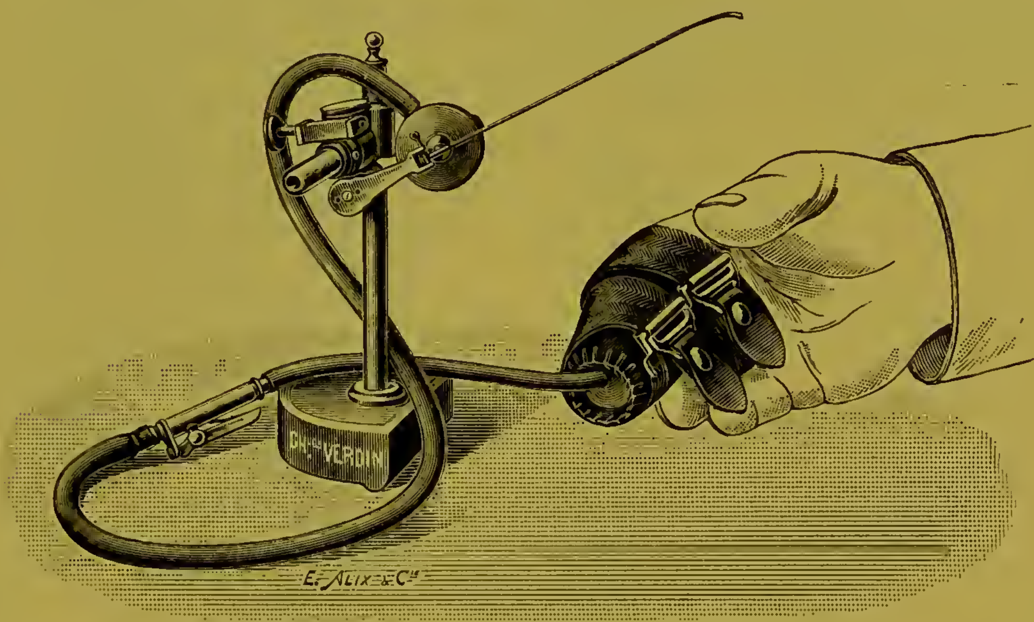


FIG. 94.—Plethysmograph of Hallion and Comte.

employed instead. This is placed loosely on the middle phalanx of one finger, and the blood pressed out of the last phalanx either by rolling a thick narrow india-rubber ring upwards, or by wrapping a piece of fine india-rubber tubing tightly round the finger from its tip upwards. (B, Fig. 97.) The pressure is then raised in the apparatus to a point which is certain to be above the pressure in the arteries, *e.g.* 200 mm. of mercury. The india-rubber ring is then rolled off or the tube unwound, leaving the last phalanx white and bloodless. The pressure is then lessened and the finger-tip watched, so as carefully to note when it begins to flush with the returning circulation. The

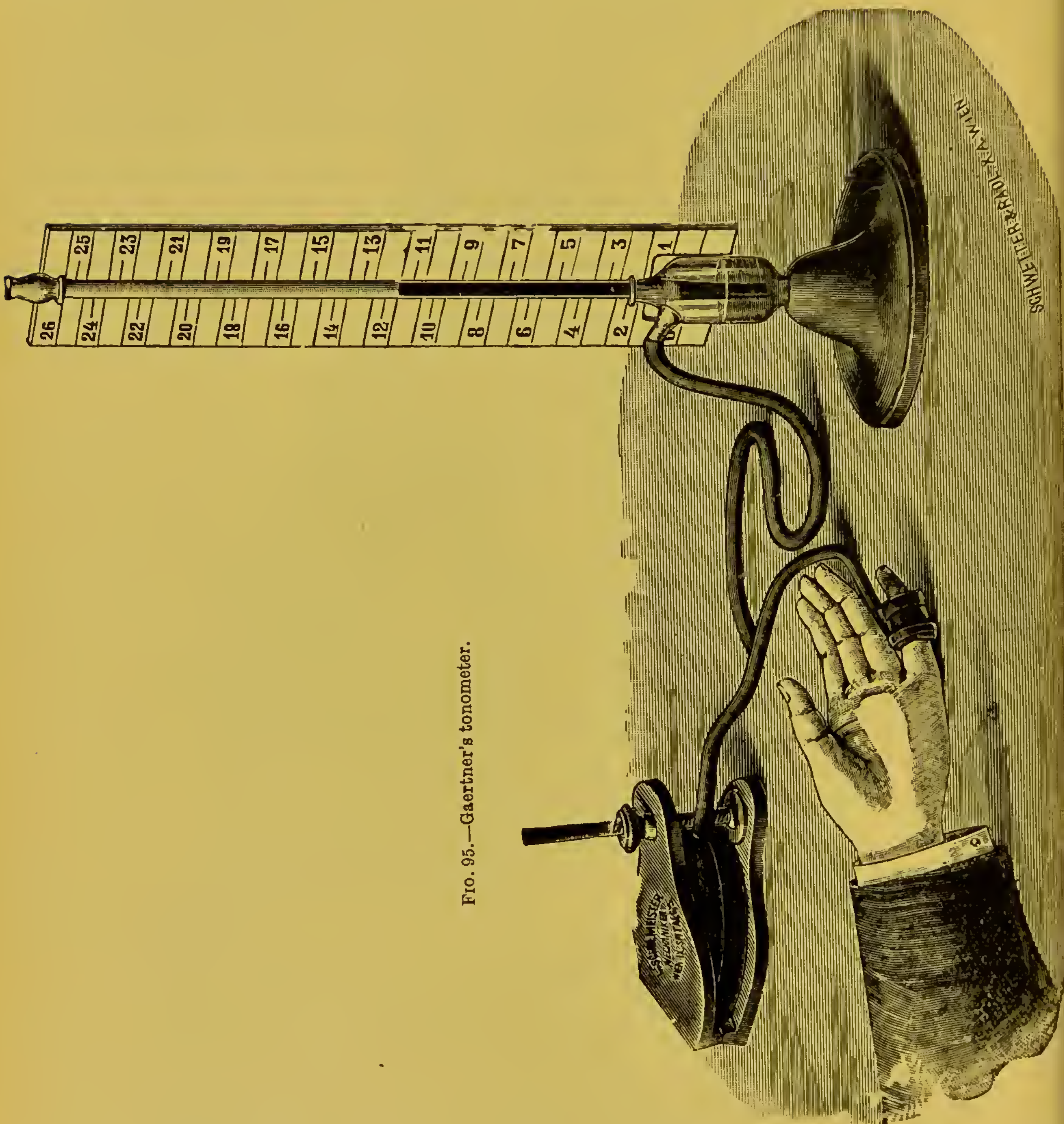


FIG. 95.—Gaertner's tonometer.

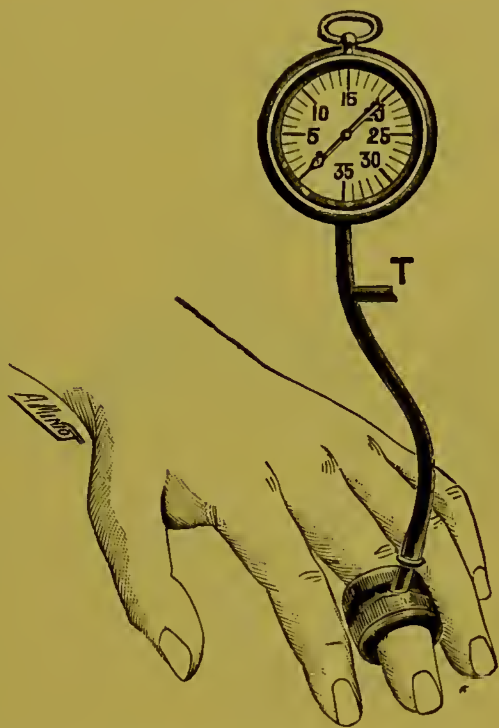


FIG. 96.—Gaertner's tonometer, portable form. T is the tube communicating with the pressure bag.

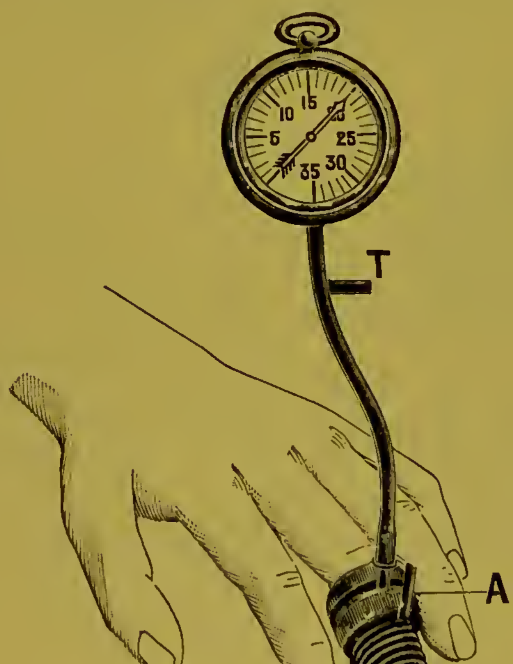


FIG. 97.—Mode of using Gaertner's tonometer. (*Vide* p. 71.)

height of the mercurial column at this moment indicates the systolic pressure in the digital arteries.

For ordinary bedside work, Professor Gaertner replaces the

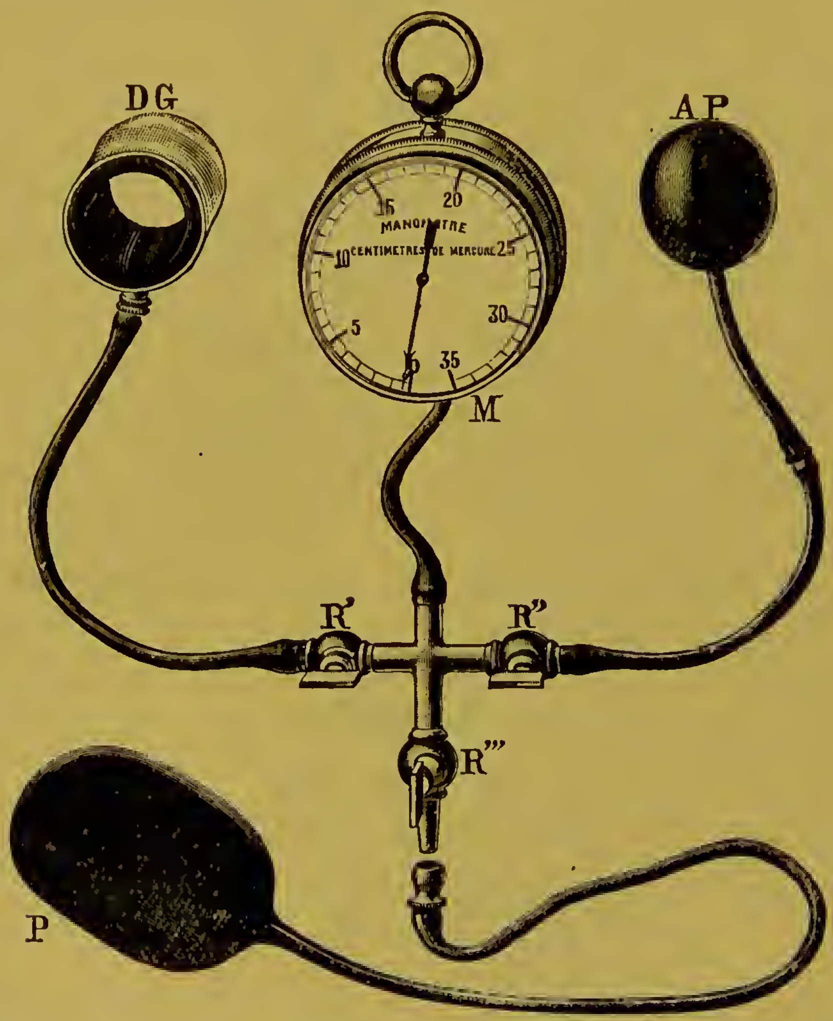


FIG. 98.—Combined Potain's and Gaertner's apparatus. AP is Potain's bulb. DG is Gaertner's tonometer. P is an india-rubber bulb containing air, by which the pressure can be raised in the tonometer. M is an aneroid manometer. R', R", and R''' are stopcocks by which communication can be established at will between the various parts of the apparatus.

mercurial by an aneroid manometer, and thus renders his instrument convenient and portable. (Fig. 96.)

LECTURE III

Measurement of the Blood Pressure in Man (*continued*): Instruments of Riva-Rocci, Hill and Barnard, Martin, and others; Author's arrangement—Systolic and Diastolic Pressures—Standardization of Instruments—Measurement of the Size of an Artery—Oliver's Arteriometer—Measurement of Pressure in the Veins—Measurement of Pressure in the Capillaries—Measurement of the Volume of Organs—Plethysmographs—Cardiographs—Sphygmographs—Forms of Sphygmograph: Marey's, Ludwig and Von Frey's, Dudgeon's, Jacquet's, Laulanié's—Size of Vessels—Cardiograph and Sphygmograph—Sphygmograms—Retardation of Pulse-wave—Nutrition of the Heart—Self-massage of the Heart—Brücke's View—Nutritive Action of Cardiac Tonics—Self-massage of the Arteries. PATHOLOGY OF THE CIRCULATION: Effect of Altered Quality of Blood—Blocking of Coronary Arteries—Effect of Feebleness of the Heart on the Nutrition of Blood-vessels—Nervous Depression—Fatty Degeneration—Pulse-rate—Exophthalmic Goitre.

PERHAPS the most practically useful of all the instruments for estimating the blood pressure in man is that invented by Riva-Rocci, with its numerous alterations and improvements. It consists of an elongated distensible but resistent bag connected with a mercurial manometer (Fig. 99). The bag is fastened round the arm and inflated by a small india-rubber hand-pump until the pressure is sufficiently great to stop the pulse. This point is noted, and the pressure is then increased a little further; air is then gradually let out, and the pressure is again noted when the pulse begins to reappear. In this way one has actually two observations made close together of the pressure which stops the flow of blood in the artery. The objections to the instrument in its original form are that the narrow band appears to give a higher reading than what is attained by a broader one, and that mercurial manometers are

always inconvenient for carrying about. Hill and Barnard have made an instrument in which these objections are avoided, by making the band broader, by making its outside of leather so that it does not yield, and its inside of thin rubber, and by employing an aneroid instead of a mercurial manometer.[1] Another modification is Martin's, in which the band is made of

FIG. 99.—Riva-Rocci's sphygmomanometer.

soft pliable metal covered with cloth, and it is sufficiently broad to overlap the elastic bag by about half an inch on either side, and thus prevent the bag being blown out to one side.[2] He has also added a convenient screw valve, by which the air may be allowed to pass out of the apparatus very slowly and the pressure to diminish very gradually. Martin retains the

[1] Hill and Barnard, *Brit Med. Journ.*, 1897, vol. ii., p. 904.
[2] C. J. Martin, *Brit. Med. Journ.*, 22nd April 1905.

mercurial manometer, so that this is inconvenient for carrying about. I have had one made which I think is more convenient than any of the others, but I can hardly claim it as my own, because it is simply a patchwork of pieces from one instrument and pieces from another. (Fig. 100.) The principle of the band is Riva-Rocci's; the broad band I have copied from Martin, but have substituted a piece of unyielding tissue which is light to carry, in place of the heavier metal; the principle of the aneroid is Von Basch's, the particular modification of it is Potain's. By combining all these parts together, however, I have obtained a very

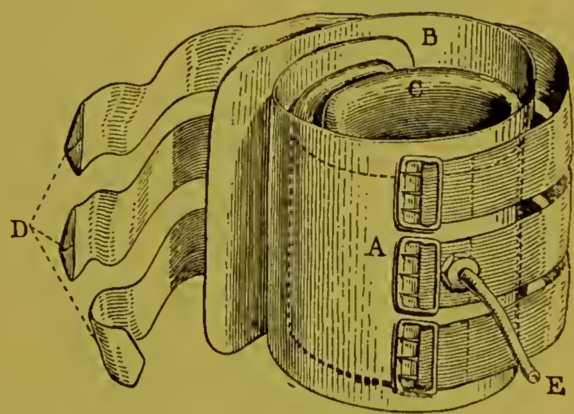


FIG. 100.—The author's modified Riva-Rocci band. A B is a band of stiff gutta percha, inside which is a narrower india-rubber bag C. D are three straps to fasten the band round the arm. E is a tube leading into the bag C, and allowing air to pass from it either to a mercurial or aneroid manometer. In using it along with the other instruments, all that is necessary is to detach the tonometer DG, Fig. 81, and replace it by the band. A spray-producer ball, like that in Fig. 81, should also be used instead of the simple bulb P, or a small one with Martin's valve may be employed. For practice one rarely needs all three, and Potain's bulb with the band and aneroid are all that are necessary.

convenient instrument by which we can in a few minutes measure the tension of the blood in the radial artery by pressure upon it with Potain's bulb, and control this observation by means of Gaertner's tonometer, or by measuring the pressure in the arm necessary to stop the radial pulse with the modified Riva-Rocci band. I have been making a number of comparative experiments in regard to the tension in man, as ascertained by different instruments, and have been rather disappointed by the want of concordance between the results. Using these three instruments together, however, I am certain of obtaining results which agree very well with one another.

Many modifications of Riva-Rocci's instrument have been

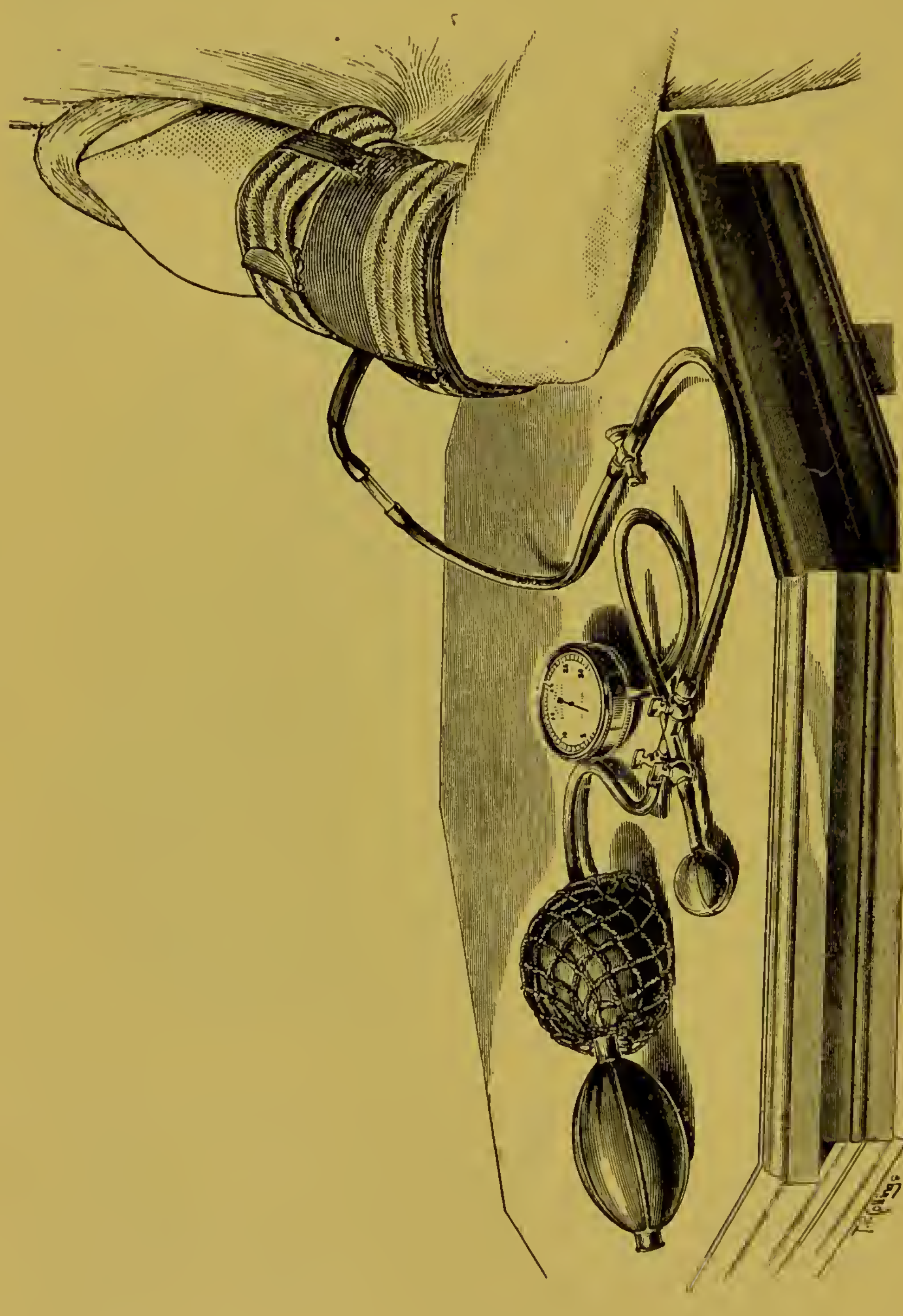


FIG. 101.—Author's arrangement for using a broad Riva-Rocci band with Von Basch's or Potain's sphygmomanometer instead of a mercurial manometer.

made and used in America. They are described by Janeway[1] in his work on *The Clinical Study of Blood Pressure*, but I do

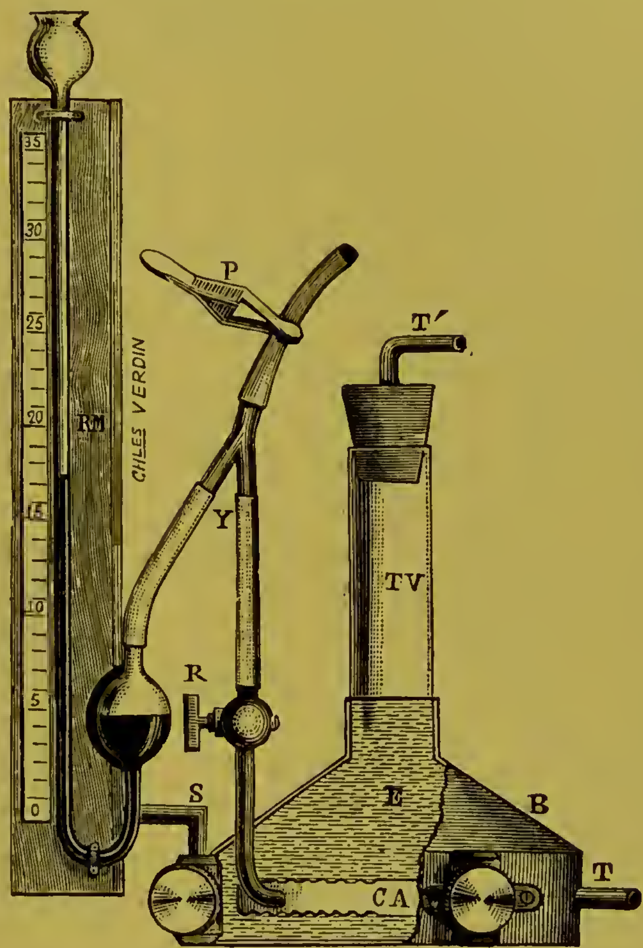


Fig. 102.—Marey's improved metallic manometer. This was originally intended to be connected to an artery, but I find it can be connected to an armlet, or used to measure the blood pressure in the same way as Riva-Rocci's, while at the same time tracings can be got of the pulse. (*Cf.* Fig. 91, p. 68.) It consists of a flat metallic vessel B, in which the capsule of an aneroid barometer filled with liquid is fixed, CA. To this leads an afferent tube T, which is put in communication with the artery, the pressure in which is to be measured. An efferent tube Y leads to a mercurial manometer, which indicates the absolute pressure and controls the readings of the metallic manometer. The metallic vessel B has at its upper part a glass tube TV, and is filled with water which rises a little way up in the glass tube. The upper part of this tube is closed by a caoutchouc stopper, through which a tube T passes; this tube is connected by a piece of elastic tubing with one of Marey's tambours, which records the oscillations of the aneroid capsule. By means of the stopcock R, the metallic may be separated from the mercurial manometer; P is a pair of pincers closing an exit tube, by which the instrument can be either emptied or filled, or the tension lowered.

not think it necessary to describe them fully here. I may merely mention that the principal are Stanton's, Janeway's,

[1] T. C. Janeway, *The Clinical Study of Blood Pressure* (New York and London : Appleton & Co.), 1904.

and Erlanger's. They are all modifications of Riva-Rocci's. Janeway's has the mercurial manometer jointed for convenience of carriage, and Erlanger's has a large sphygmoscope attached, which enabled the alterations in pressure to be recorded on a revolving cylinder in somewhat the same way as Marey's instrument. (Figs. 91 and 102.)

Systolic and Diastolic Pressures.—The point of maximum oscillation indicates the diastolic pressure, the point of obliteration indicates the highest systolic pressure, and I find the relation which these bear to one another is usually as 4 to 5, or 80 to 100, though sometimes as 4 to 6.

The systolic pressure shows the maximum height to which the blood pressure is raised by the wave of blood driven into the aorta by the contraction of the left ventricle. It thus indicates in a general way the strength of the ventricle. The diastolic pressure shows the minimum to which the blood pressure sinks during the interval when no blood is coming into the aorta from the heart, and the arterial system is emptying itself through the capillaries into the veins. It therefore indicates generally the degree of contraction or relaxation of the capillaries. A glance at Figs. 183 (p. 153) to 186, which are reproductions of tracings taken with a mercurial kymograph from the carotid arteries of dogs, will show at once how greatly the relation between the systolic and diastolic pressures and the relation of both of them to the general blood pressure may differ under different circumstances. Thus, in Fig. 183, the systolic maximum is 94 and the diastolic minimum is 54, or, roughly, as 5 to 2. In Fig. 184 the systolic maximum is 100 and the diastolic minimum 62, or, roughly, as 5 to 3. In Fig. 185 the systolic is 106 and the diastolic 78, or, roughly, as 5 to 4. The great oscillation in Fig. 182 may be partly due to inertia of the mercurial column (*cf.* Fig. 73), but only to a slight extent. In Fig. 186 the normal systolic is to the diastolic pressure as 5 to 4, but after stoppage of the heart by irritation of the vagus it is nearly as 3 to 1.

Standardization of Instruments.—As an aneroid manometer is apt to become altered by use, it is well to compare it frequently with a mercurial one, and this can be done in less

than five minutes, by connecting both by means of a T-piece with a spray-pump, raising the tension by 5 mm. at a time, and noting the correspondence or difference in the readings of the two instruments. (Fig. 103.)

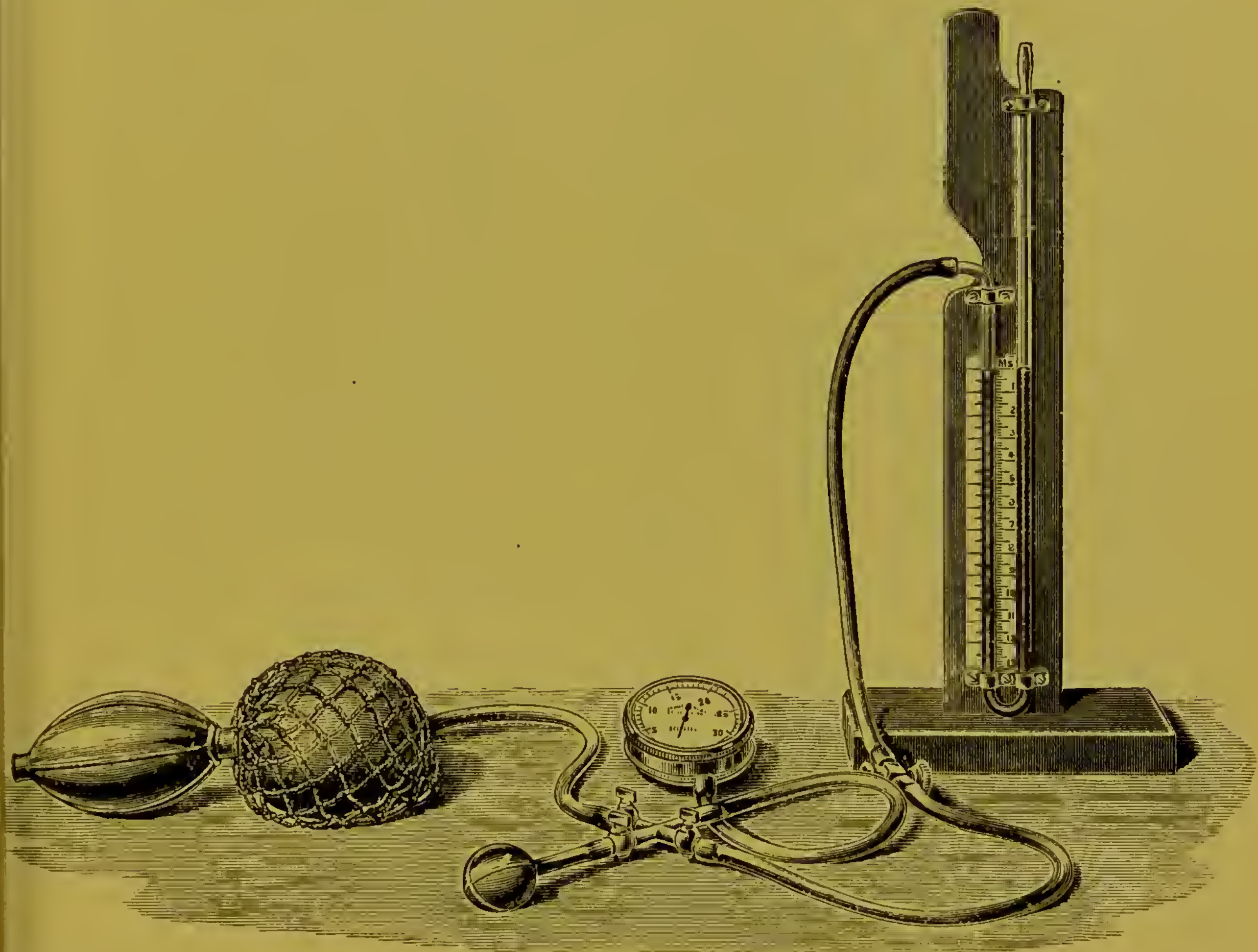


FIG. 103.—Author's apparatus for ascertaining the correctness or amount of error in an aneroid sphygmomanometer. By means of a three-way stopcock both the aneroid and a mercurial manometer are put into communication with a pressure bulb of a spray apparatus. The pressure is then raised 5 mm. at a time, and the readings of the mercurial and aneroid compared at each pressure.

Size of Vessels.—A most ingenious instrument for measuring the size of the arteries has been devised by Dr Oliver, and is called by him the arteriometer.

Measurement of Pressure in the Veins.—This may be done by choosing any convenient portion of a subcutaneous vein and pressing an instrument such as Figs. 78, 85, 87, or 88 upon its distal end with sufficient force to stop the flow of blood. The

proximal part is then emptied of blood by pressing the tip of a finger along it. The pressure of the pad or bulb is then relaxed, and the pressure noted at which the vein again fills.

A simple way of roughly estimating the venous pressure is to notice at what height above the level of the heart the veins of the hand become empty. Normally, they should do so about the level of the third rib, or a little above. The greater the venous pressure the higher must the hand be raised.

Measurement of Pressure in the Capillaries.—The method of doing this we owe to Ludwig (N. v. Kries, *Ludwig's Arbeiten*, 1875, p. 69). It consists in laying on the skin a piece of glass of a definite size, which can be pressed down with more or less force, and noting the lowest pressure at which the skin becomes white. The pressure can be applied by a weight or by a spring. (Fig. 80.) The pressure may be measured anywhere, but the back of a finger or the lobe of the ear is most suitable. The pressure varies with the height at which the hand is held. When level with the top of the head, it is about 24 mm. of mercury (328 of water); 8 inches below this, 28 mm. (397 of water). In the ear it is about 20 mm. of mercury (272 mm. of water).

Cardiograph and Sphygmograph.—All the instruments I have hitherto described have been chiefly for measuring the

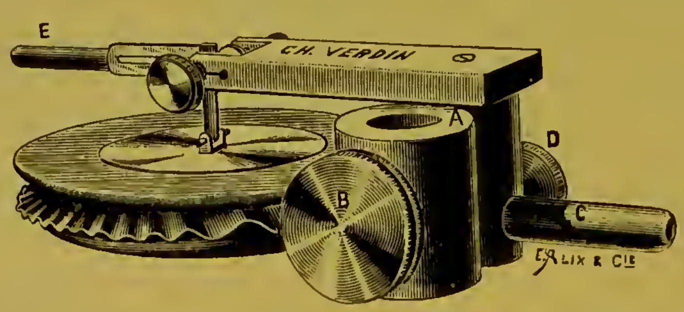


FIG. 104.—Marey's tambour for recording movements. It is a metal ring which slides on an upright rod, and can be fixed at any height by the screw B. C is the tube through which the air from the receiving instrument (sphygmograph, cardiograph, etc., communicates with that inside the tambour and causes the cover E to rise or fall. Into E a long straw is fastened bearing a point which records its movements on a cylinder.

amount of blood pressure, or the size of the artery, but they do not give us any indication of the mode of contraction of the heart or the nature of the pulse-wave. These have chiefly been

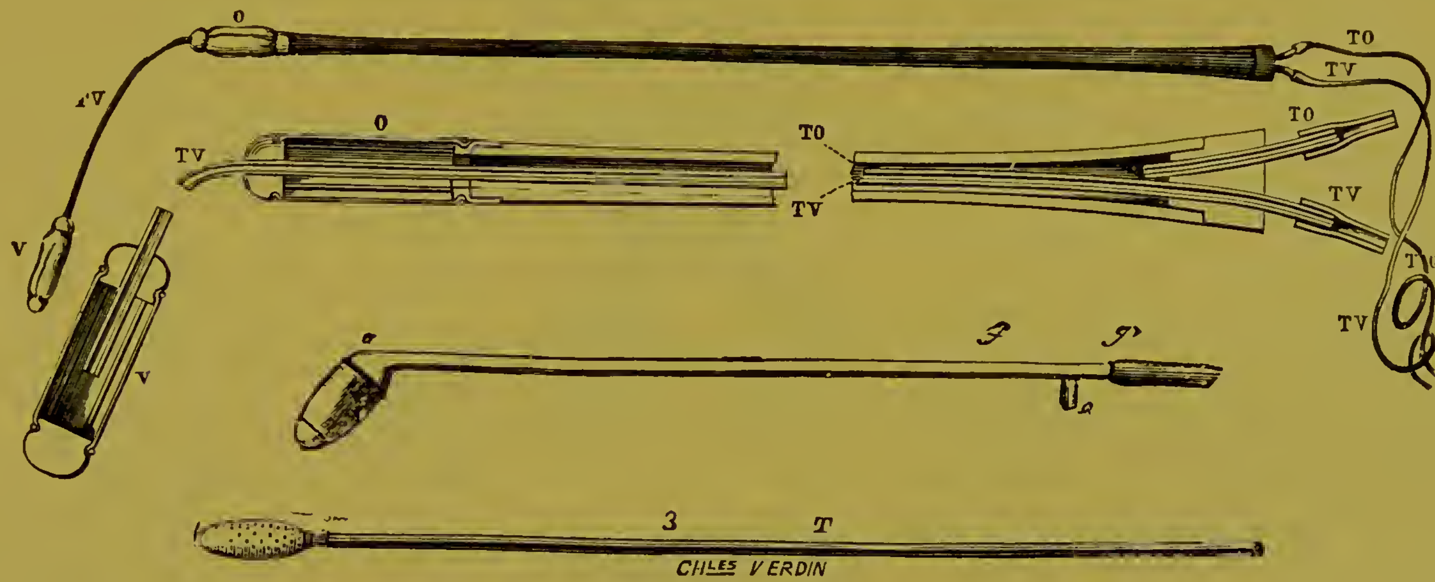


FIG. 105.—Cardiac sounds by which the tracings, Fig. 108, were obtained. V is a bulb which is introduced into the right ventricle, and communicates by a tube, T V, with a tambour (Fig. 104). O is another bulb, which is placed in the auricle, and communicates by a tube, T O, with another tambour. These tambours register the intra-ventricular and intra-auricular pressures. *a f* is a sound for the left ventricle, communicating with a tambour by the tube *g*.

worked out by instruments devised by the late Professor Marey, and the principle upon which most of them depend is that of the transmission of motion by air from one elastic vessel to another. The recording vessel consists of a shallow metal dish covered at the top by a piece of thin india-rubber. (Fig. 104). Over this rests a light lever, and the movements of the rubber are thus greatly amplified, are rendered visible to the eye, and can also be recorded on a revolving cylinder. The elastic vessel by which the movements are received varies in shape according to the purpose it is required to serve. For the heart it is a long metal bulb with openings in its sides over which the thin india-rubber is tied. (Fig. 105). For the apex beat it may be simply a tambour with a spring to press it against the chest wall (Figs. 106

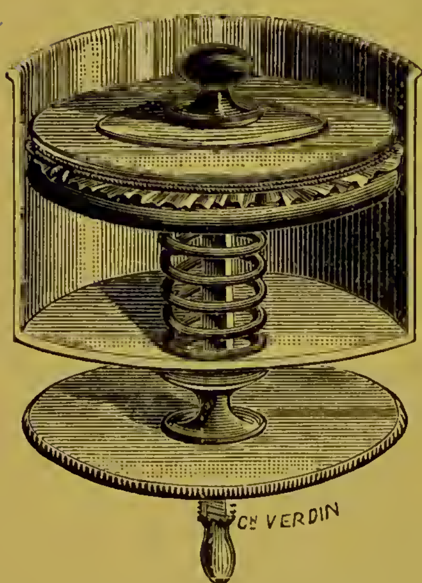


FIG 106.—Marey's cardiograph.

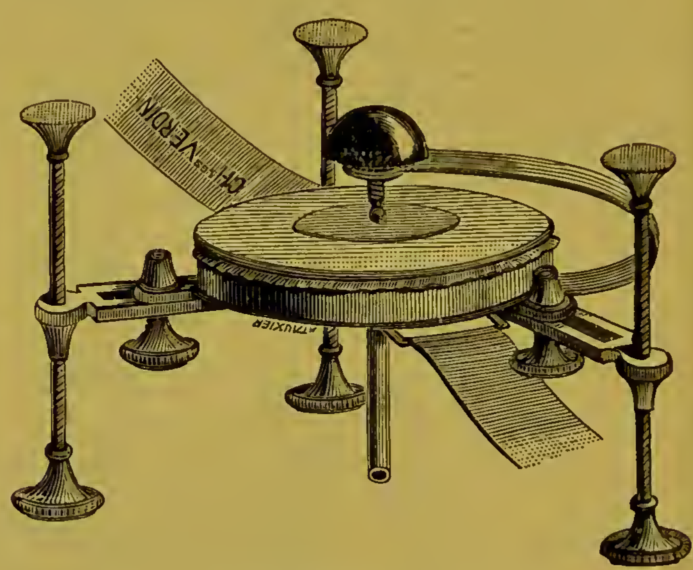


FIG. 107.—Burdon-Sanderson's cardiograph for the apex beat.

and 107), and for the pulse a tambour with a spring attached, which rests upon the pulse and transmits its movements to the receiving tambour (Fig. 122). The air within this is, of course, alternately condensed and rarefied, and each movement is faithfully transmitted to the recording tambour (Fig. 104). By introducing one of the elongated bulbs just mentioned through the aortic valves into the ventricle, Marey obtained tracings of the changes in pressure throughout the ventricular cycle, as shown in Fig. 108. There is first a slight rise, due

to the auricular contraction, then a sudden rise, which becomes somewhat slower as it increases. At the top of this is a plateau showing several oscillations, then a sudden descent, marked at its end by a little wave, and then an almost level line, after which the same sequence again occurs. The alteration in rapidity of ascent which takes place about the middle of the systole probably indicates the time at which the auriculo-ventricular valves become screwed together, and the aortic valves are forced open by the increasing pressure behind. The

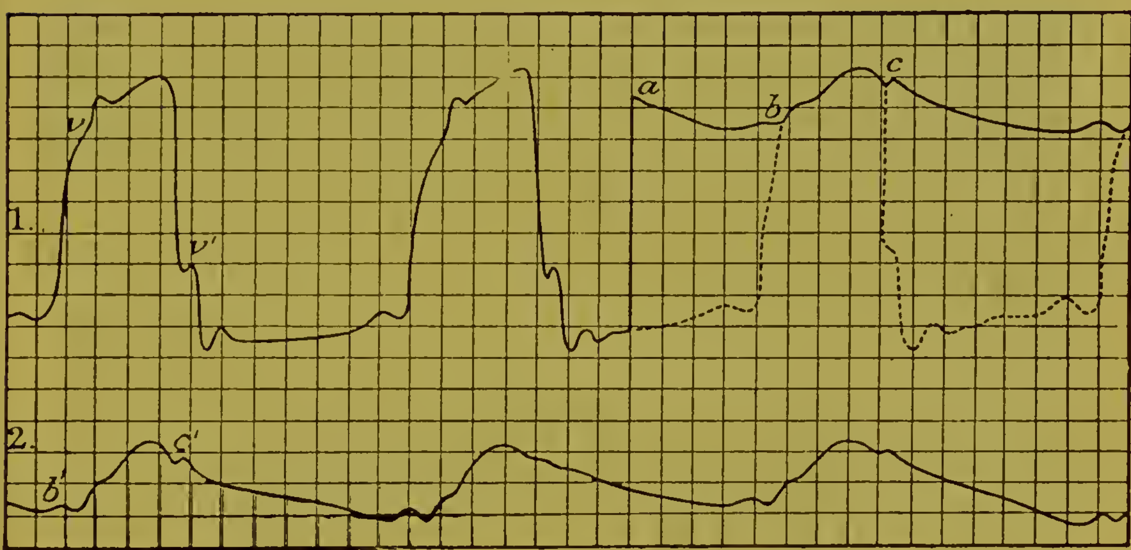


FIG. 108.—Tracings of the ventricular systole (1) and of the aortic pulse (2). In the first tracing a manometric sound was placed in the left ventricle; after two beats it was withdrawn at *a* from the auricle into the aorta. The second tracing is obtained from a manometric sound placed permanently in the aorta. The part *b c* and *b' c'* is common both to the ventricular and aortic tracing. At this point the aortic valves are open and the ventricle and aorta are in free communication; *b'* in the second tracing marks the point where the blood begins to flow into the aorta; *v* marks the point where the mitral valves and *v'* where the sigmoid valves close.

oscillations which occur on the plateau, according to Marey, do not indicate mere vibrations of the auriculo-ventricular valves, but real oscillations in them and in the blood on both sides of them. The sharp fall indicates the diastolic relaxation of the ventricle, and the little wave at the end marks the time of closure of the sigmoid valves.

When the bulb is withdrawn from the ventricle into the aorta, a tracing is obtained which is almost exactly like that of the ventricle with the lower part of it cut off and a gradual descent substituted for the sudden fall. (Fig. 108, 1 (*a*, *b*, and *c*), and 2).

FIG. 109.—Diagram to show the analogy of the senile pulse to the ventricular beat. (After Marey.)

FIG. 110.—Sphygmogram showing the effect of increased tension on the pulse. The first half was taken while both femoral arteries were compressed. The latter half after the tension had been reduced by ceasing the compression. (After Marey.)

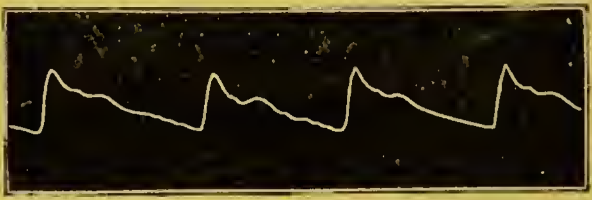


FIG. 111.—Tracing of a normal pulse.

FIG. 112.—Shows three tracings of a healthy pulse with varying degrees of tension. In 1 the tension is high owing to the contraction of the arterioles from cold; 2 and 3 show diminished tension from warm clothing causing relaxation of the arterioles. (After Marey.)

If the aorta were rigid, this form of curve would be transmitted on to the periphery, and we do, indeed, find that the

FIG. 113.—Effect of fever on the pulse; 1 is a tracing taken during fever; 2 is one from the same patient when the fever was absent. (After Marey.)

radial pulse tracing shows the characters of the aortic pulse, namely, the flattened plateau, and slow, rather even, descent

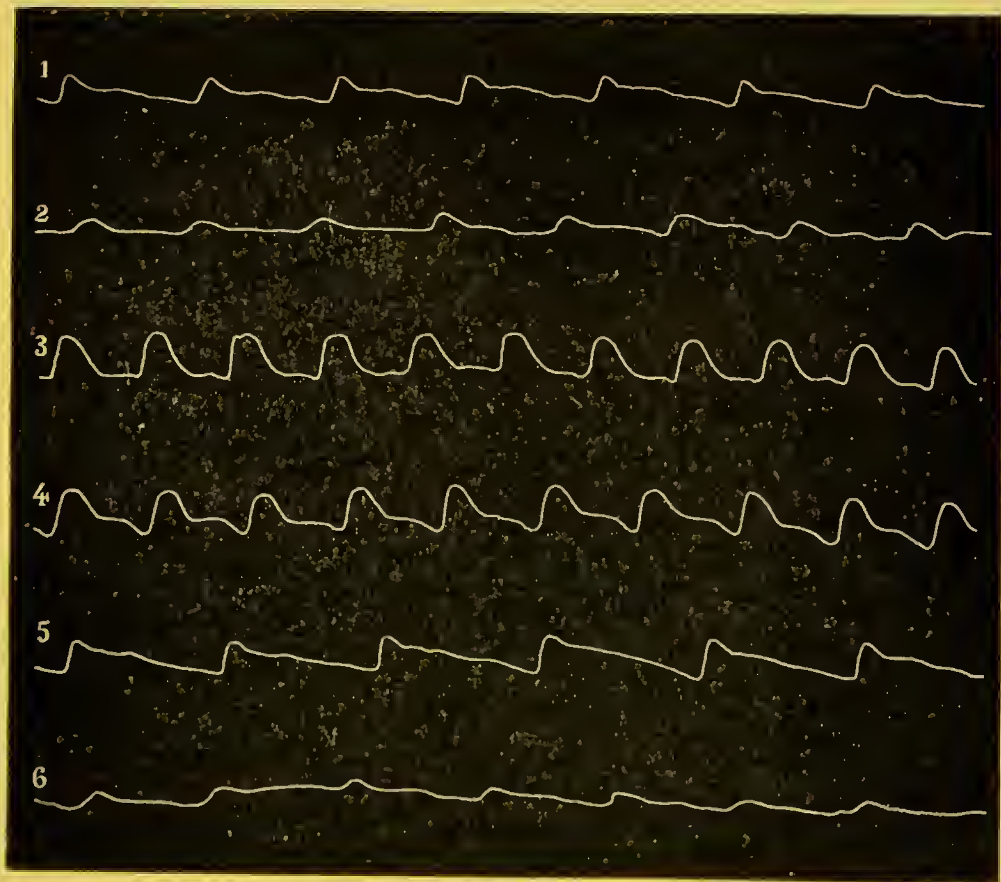


FIG. 114.—Tracings of the pulse at different stages of intermittent fever:—1. Pulse in apyrexia; 2. Stage of chill; 3 and 4. Hot and sweating stages; 5. Apyrexia; 6. Another chill.

whenever the elasticity of the arteries is impaired by atheromatous change, as in old people (Fig. 109), or by great disten-

sion from high arterial pressure (Fig. 110), as in cases of Bright's disease.

Sphygmograms.—In ordinary healthy people the elasticity of the aorta and arterial walls is sufficient to modify the tracing very greatly, and in healthy people the sphygmogram has the following characters:—A fairly sudden and extensive rise

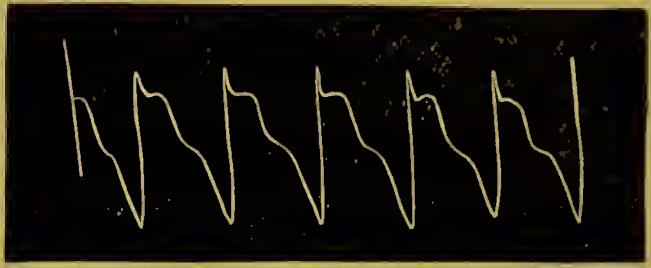


FIG. 115.—Tracing from a case of aortic regurgitation, showing hook at top of tracing, sudden fall and extensive movement.

followed by a moderately quick fall for a certain distance, then a second rise and then a second slower fall. (Fig. 111.) Whenever the vessels are empty, so that the blood is driven in quickly during systole, the rise is sudden. (Fig. 115.) When the vessels are full and tense, so that the blood pressure within them is high and blood is driven in slowly, the rise is slow. (Fig. 112, 1; 114, 1, 2, and 6.) The same form of tracing may, to a

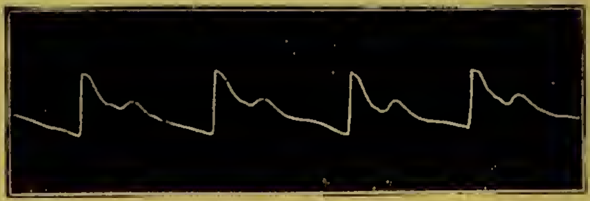


FIG. 116.—Tracing showing dichrotism.

certain extent, also come from the feeble heart. The arteries may be empty from aortic regurgitation, when the blood flows backwards from the heart; or from capillary dilatation, when it flows rapidly onwards into the veins. (Fig. 112, 3; 113, 1.) In the former case the fall is, as a rule, very sudden at the commencement, and the movements are very extensive. (Fig. 115.) In the latter, the fall is more gradual. In both

FIG. 117.—Radial pulse before a hæmorrhage. (From Marey, after Lorain.)

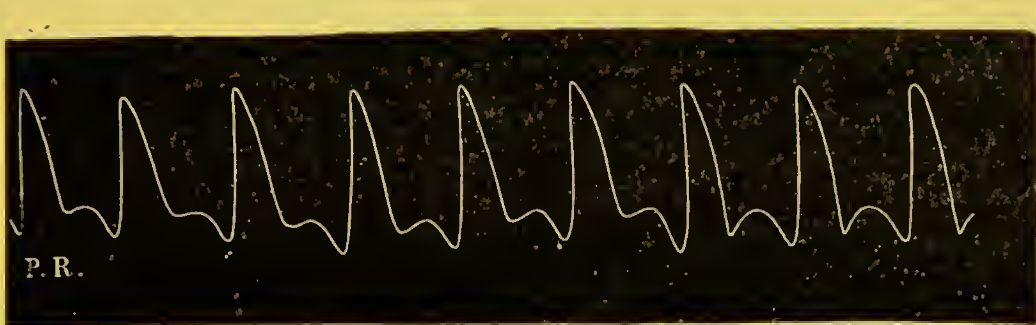


FIG. 118.—Radial pulse from the same patient, after a hæmorrhage. (After Lorain.)

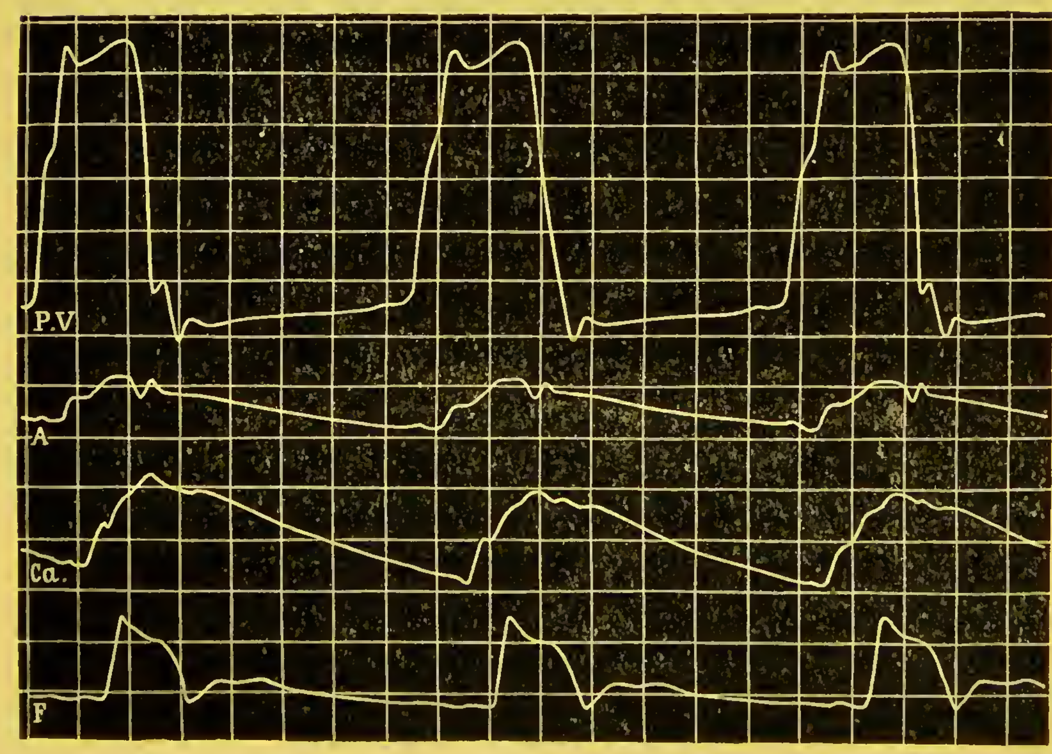


FIG. 119.—Retardation of the pulse in different arteries. P V, curve of pressure in the ventricle of the horse. A, aortic pulse. Ca, carotid pulse. F, femoral pulse. Each square corresponds horizontally to one-tenth of a second. (After Marey.)

cases, however, the lever of the tambour may be raised so suddenly that its own inertia carries it beyond the point to which it ought to go, and a little crochet or hook is formed at the summit of the tracing. (Fig. 115.) A great deal of trouble has been taken to ascertain the exact cause of the second, or dicrotic wave, as it is termed, on the descending limb of the sphygmograph tracing. (Fig. 116.) I shall not attempt to go into this question here, but I shall merely say that exaggeration of the dicrotic wave means increased power of the heart in relation to the resistance it has to overcome, just as when I take this elastic ball and strike it against the floor, it rebounds higher the more force that I use. When the aortic valves are incompetent, however, as a rule we do not get this rebound, and the commonest cause of dicrotism is relaxation of the capillaries or arterioles. The most marked tracing of it that I ever obtained was from a youth who had had very profuse hæmoptysis, so that he had become almost drained of blood. (*Cf.* Fig. 118.)

Retardation of Pulse-wave.—The pulse-wave takes a certain time to travel from the heart to the periphery (Fig. 116), and if the heart is acting quickly this retardation may make the radial pulse coincide with the cardiac diastole rather than the systole, and the carotid pulse should be used and not the radial to fix the time of cardiac murmurs.

Forms of Sphygmograph.—There are a number of forms of sphygmograph: Marey's original one (Fig. 120); Marey's as

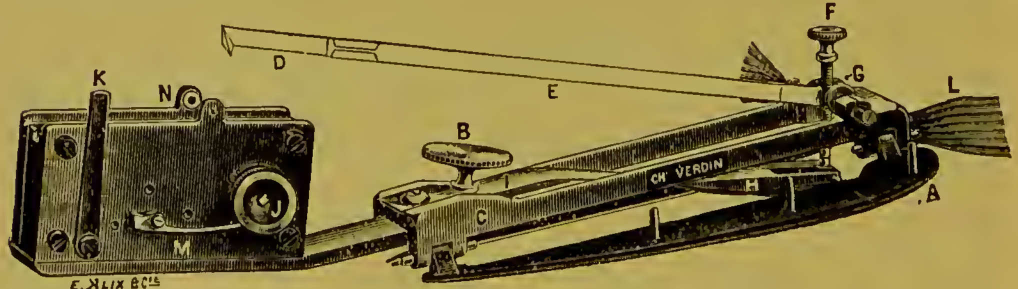


FIG. 120.—Marey's sphygmograph.

modified by Ludwig and Von Frey; Marey's sphygmograph for transmission (Fig. 122), which is very convenient when one wishes to get simultaneous tracings of the heart, radial pulse,

and sometimes also of the large veins; Dudgeon's (Fig. 123), which, though perhaps less accurate, has come much into use on

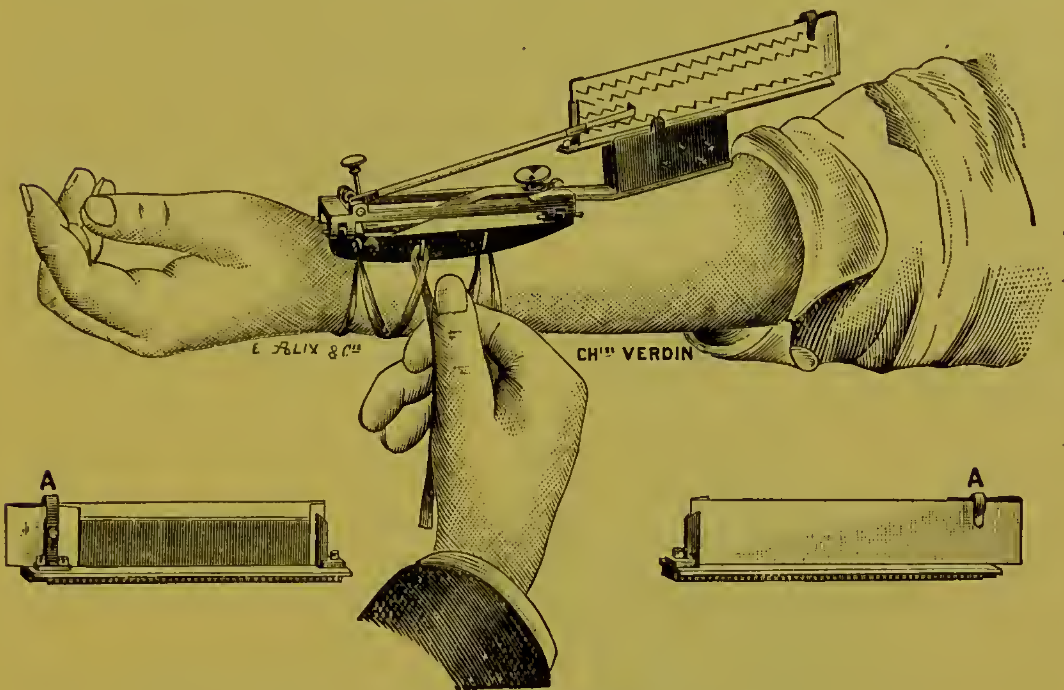


FIG. 121.—Mode of applying Marey's sphygmograph.

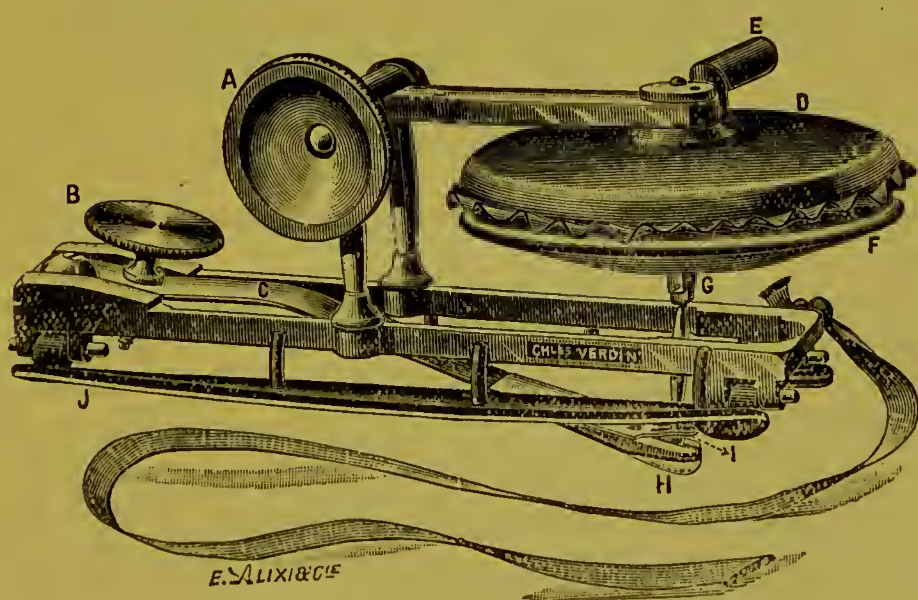


FIG. 122.—Marey's transmitting sphygmograph.

account of its great convenience, readiness of application, and portability; Jacquet's, which is like Dudgeon's, but is provided

with a time-marker; and Laulanié's, which can be used on a finger. (Fig. 124.)

The sphygmograph has given us much useful information regarding the circulation, but has not become so extensively used clinically as one expected forty years ago. (*Vide* Figs. 204 to 214.) No doubt this is to a great extent due to the very different tracings that are obtained according to the mode of application, although when one is accustomed to use it regularly the fallacies which would thus be introduced are greatly lessened, and I think it quite possible that the sphygmograph may again be used more frequently, if employed in com-

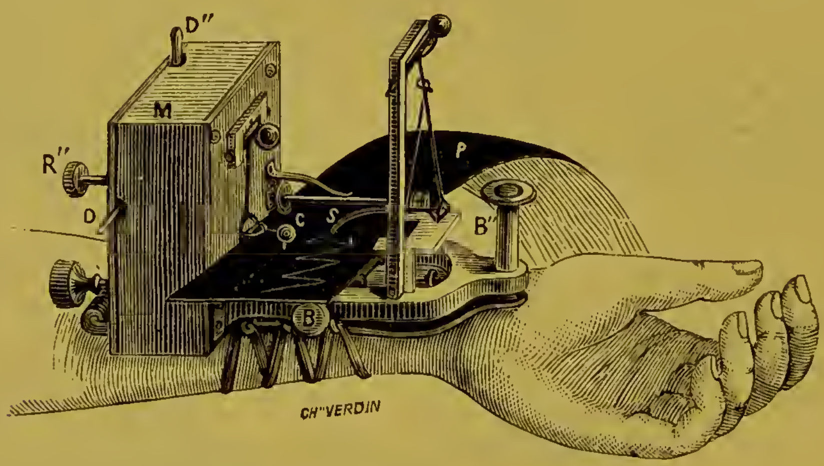


FIG. 123.—Dudgeon's sphygmograph.

bination with some instrument for estimating exactly the arterial tension.

Nutrition of the Heart.—The power of the heart to contract quickly and powerfully depends, like that of the skeletal muscles, on its nutrition, and this is regulated to a great extent both by the quality and quantity of blood it receives. The heart is like the priests of old, who took the best parts of the offerings before the remainder was distributed to the people. For the coronary arteries leave the aorta just above the sigmoid valves, and consequently they get the first portion of blood as it comes fully arterialised from the lungs, and, as Sir R. Douglas Powell has pointed out, the heart is thus almost more dependent than other organs upon proper pulmonary aëration.

The right coronary artery supplies chiefly the right side of

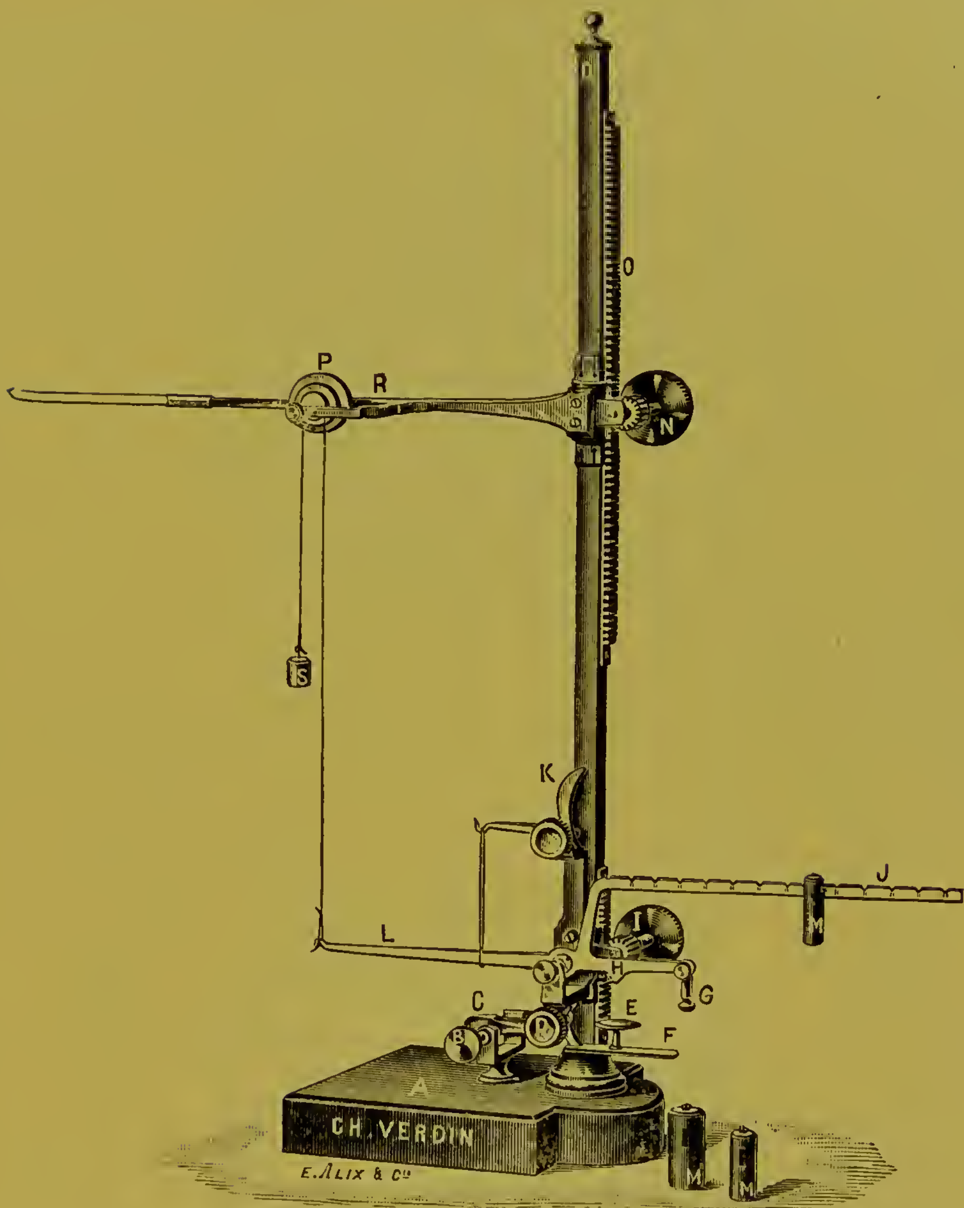


FIG. 124.—Laulanié's digital sphygmograph. E, disc on which the pulp of the finger rests. L, aluminium lever which rests by its projection H on the root of the nail. M is a movable counterpoise which can be moved along the rod J so as to exert on the finger the proper amount of pressure required to obtain the maximum oscillations of the lever. P, pulley with a writing point to magnify the movements of the lever L. G is a rod terminating in a button for taking the radial pulse. In doing this the disc E and the rod F which carries it are moved out of the way, and a heavier counterpoise is employed. K is a bent rod which permits of an india-rubber band being employed instead of the counterpoise. N is a milled head which allows the rod R to be moved up and down on the stem O, and tracings taken at different heights on a revolving cylinder.

the heart. The left coronary artery supplies both the left auricle and ventricle and also part of the right ventricle. The

terminal branches of the two coronary arteries communicate, but not freely enough to maintain circulation, if one of the arteries be closed, although no doubt differences in this respect exist in different animals, and probably in different men. When an artery is closed very slowly, the communication with the other one may gradually become sufficiently increased to maintain the circulation after the first has become completely occluded; and the vessels of Thebesius, at least in the dog, may maintain the circulation even after both coronary vessels have been obstructed. In consequence of this, if one artery be ligatured the heart usually ceases to beat, and the same occurs if an embolism should obstruct the artery. If one artery be narrowed by atheroma, that part of the heart which it ought to nourish is apt to undergo fatty degeneration, and one can readily see that, even if the artery remains of its proper size, it may become relatively too small for a heart which has undergone hypertrophy.

Self-massage of the Heart.—In speaking of the venous circulation in the limbs, I mentioned that the muscular movements

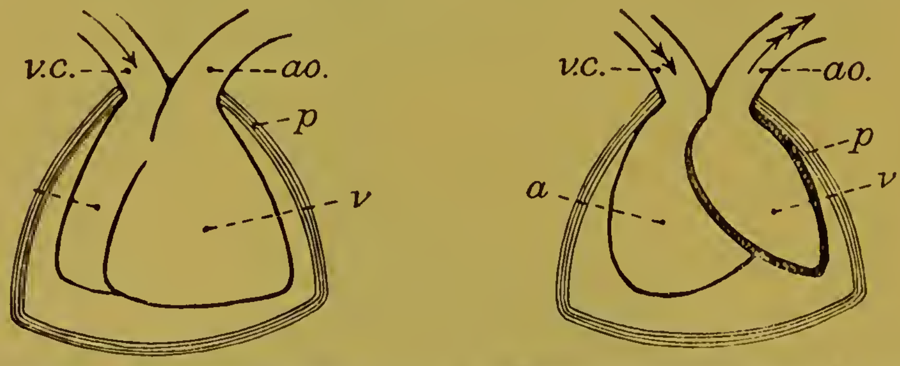


FIG. 125.—Diagram to illustrate Brücke's view of the suction action of the ventricular systole in drawing blood from the veins into the auricle. In both figures *p* is the pericardium, *v* the ventricle, *a* the auricle, *a o* the aorta; and *v c* the vena cava. For the sake of simplicity only one auricle and ventricle are represented.

tend to aid the return of venous blood, and the same thing occurs in the heart; for, during the contraction of the ventricle, blood is pressed out mechanically from its vessels, and during diastole the arteries are filled again at high pressure with blood from the aorta. The same thing probably happens also with regard to the lymphatics, which run alongside of the coronary arteries.

As Brücke pointed out in one of his lectures, which I heard in Vienna in 1867, the pericardium may be likened to a bell jar, the walls of which are more or less rigid, the pericardium being attached to the tissues all round it. (Fig. 125.) When the ventricle

FIG. 126.—Diagram of a transverse section of the thorax during inspiration and cardiac systole. It shows the tendency to the formation of a vacuum in the pleural and pericardial cavities.

contracts, it tends to produce a vacuum in the pericardium, and thus not only to suck blood into the auricles, but to exert suction upon the ventricle itself, and thus to draw plasma from

FIG. 127.—Diagram of a transverse section of the chest during expiration and cardiac diastole, showing the pressure of the walls of the pleural and pericardial cavities against each other.

the blood-vessels into the cardiac muscle, and also lymph into the pericardial space. When the heart dilates again in diastole it tends to press the lymph out of the pericardium, and thus

keeps the pericardium always moist without any accumulation of fluid occurring. The alternate contraction and dilatation of the heart thus keep up what we may term a sort of self-massage, by which both the circulation of blood and of lymph in and around it are properly maintained (Figs. 126 and 127.) It is evident, therefore, from what I have just said, that the maintenance of the heart's nutrition depends greatly upon its own activity, and this is a point of extreme practical importance.

Nutritive Action of Cardiac Tonics.—We can thus see that, in cases where the nutrition of the heart is failing, drugs which

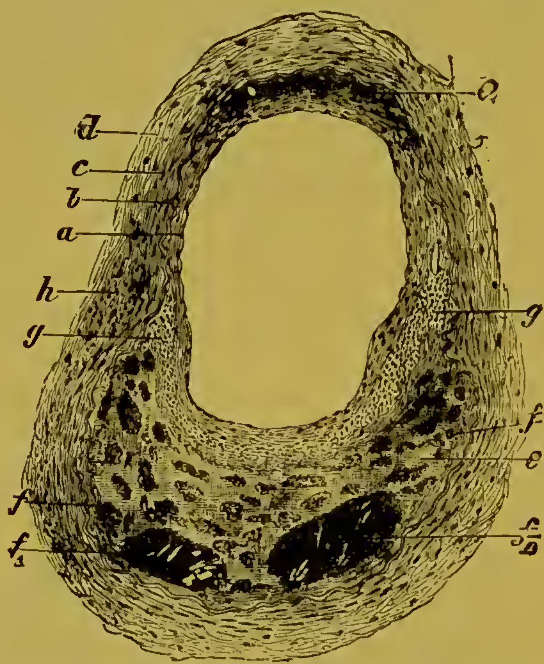


FIG. 128.—After Ziegler. Section of an atheromatous cerebral artery. *a*, intima considerably thickened; *b*, bounding elastic lamella of intima; *c*, media; *d*, adventitia; *e*, necrosed denucleated tissue with masses of fatty detritus; *f* and *f*, detritus with cholesterin tablets; *g*, infiltrated leucocytes in the intima; *h*, infiltrated leucocytes in the adventitia.

stimulate it to increased action do not act merely temporarily as cardiac stimulants, but that they are really at the same time cardiac nutrients. It is because of this fact that the good effects which we see from the use of strychnine, digitalis, strophanthus, caffeine, etc., in cardiac disease do not cease when the drugs are withdrawn, but may continue and increase, these drugs having given a temporary increase to the power of the cardiac muscle which has enabled it to nourish itself more efficiently.

Self-massage of the Arteries.—Now, a very important set of vessels in the body are the *vasa-vasorum*, the blood-vessels which supply other blood-vessels. When these undergo change, so that the blood-vessels themselves are badly nourished, the condition of the circulation generally becomes very precarious, for there is a great deal of truth in the old saying, that "a man is as old as his arteries." When his arteries become atheromatous (Fig. 128) or calcareous, the termination of the man's life is not likely to be very far off. But the arteries also have a power of self-massage. The hard fibrous tissue which forms their sheath usually envelops not only the artery and vein, but also the lymphatics. Between the intima and media of the artery, and probably in the media itself, there are lymphatic spaces, and in the adventitia there are distinct lymphatic vessels. The

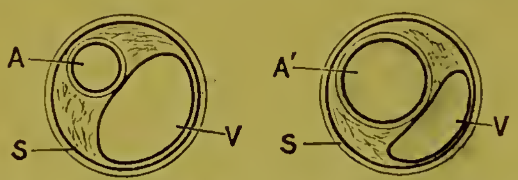


FIG. 129.—Artery and vein in common sheath, to show the effect of the arterial pulse in aiding venous circulation. A, artery in diastole. V, distended vein. S, common sheath. A′, artery distended by the cardiac systole. V′, the vein compressed and partially emptied of blood.

alternate distension and relaxation of the arterial wall at each pulsation not only drives blood and lymph onwards towards the heart at each beat of the heart, but, during the diastole, as the blood runs out of the artery, there is a tendency for the arterial coats to separate from one another, and thus draw in fresh supplies of blood into the *vasa-vasorum*, and of plasma from them into the arterial walls. (Figs. 129 and 162.)

PATHOLOGY OF THE CIRCULATION

Effect of altered Quality of Blood.—However good the circulation may be through the heart or vessels, they will suffer if the quality of the blood is bad. Thus, fatty degeneration of the heart is found in acute and chronic anæmia, in old age, in failing nutrition from disease, and from various poisons, *e.g.* in chronic alcoholism, or after the administration of chloroform,

arsenic, or phosphorus. But a very frequent cause are the toxins which occur in various diseases, especially those of the infective fevers. Sometimes these toxins, instead of producing fatty degeneration, cause a general softening of the muscular tissue or parenchymatous degeneration, in which the muscular cells become degenerated but not fatty.

Blocking of Coronary Arteries.—Partial blocking of a branch of the coronary artery may produce a local necrosis of the cardiac wall, causing either sudden death or the formation of a fibrous patch. When the coronary arteries undergo gradual closure, the muscular tissue they supply either undergoes fibrous

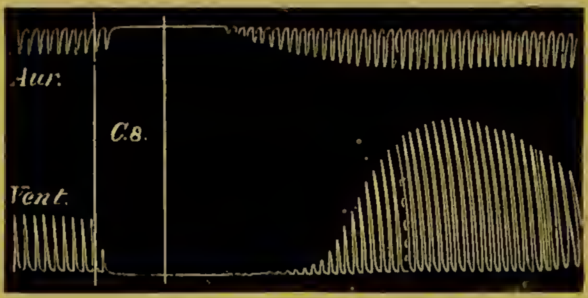


FIG. 130.—After Gaskell. Tracing showing stoppage of the heart by stimulation of the vagus. *Aur.* indicates the auricular, and *Vent.* the ventricular tracing. The part included between the upright lines indicates the time during which the vagus was stimulated. *C.*8 indicates that the secondary coil used for stimulation was eight centimetres distant from the primary. The part of the tracing to the left hand shows the regular contractions of moderate height before stimulation. During stimulation, and for some time after, the movements of both auricle and ventricle are entirely arrested. After they again commence, they are small at first, but soon acquire a much greater amplitude than before the application of the stimulus.

change or fatty degeneration. In either case the heart is much weakened; and in chronic valvular disease, and in old people, brown atrophy is common.

In the arteries, as in the heart, interference with the blood supply causes degeneration. In one form—the nodular form—there is inflammation in and around the arterial coats with local infiltration about the *vasa-vasorum*, leading to spots of degeneration, and formation of an atheromatous button, or a patch of nodular arterio-sclerosis. In old people the arterial walls become stiff, and are often as rigid as pipe-stems from calcareous deposit, while the tissue underneath the intima may break up and form rough atheromatous ulcers. One of the most important changes of all is the diffuse arterio-sclerosis, or as

Gull and Sutton call it, arterio-capillary fibrosis, in which the wall becomes thickened from a deposit of hyaline tissue between the muscular and the endothelial coats. This deposit, which is so liable to occur in kidney disease, is of great importance, because a lessening of the lumen of the arterioles increases the peripheral resistance, leads to hypertrophy of the heart, and thus to an enormous increase in blood pressure, with consequent danger of rupture and apoplexy.

It is evident that thickening of this sort is not likely to yield readily to vascular dilators, and that consequently one may not be able to reduce the tension in a case of gouty kidney by vascular relaxants, such as the nitrites, to the same extent that one would expect if the increased tension had been

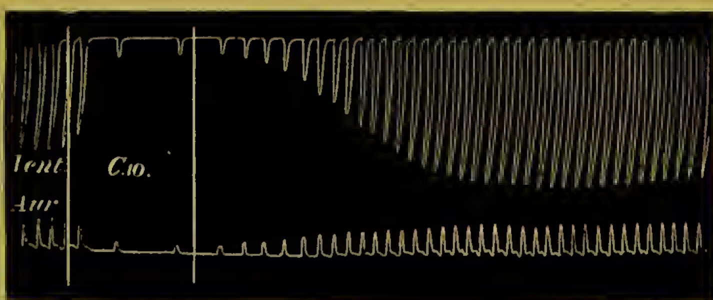


FIG. 131.—After Gaskell. Tracing showing diminished amplitude and slowing of the pulsations without complete stoppage, during irritation of the vagus.

dependent upon spasm of the muscular coats of the arterioles alone. It is clear, therefore, that more permanent good is to be hoped for from such drugs as cause absorption, and especially from iodides, than from vascular dilators alone. At the same time this high tension either depends to a certain extent on muscular spasm or does not affect the whole of the vessels equally, because nitrites will reduce the blood pressure to a certain degree in such cases.

Effect of Feebleness of the Heart on the Nutrition of Blood-vessels.—From what I have said regarding self-massage of the arteries, veins, and lymphatics within their common fibrous sheath, it is evident that smallness of the pulse-wave and imperfect expansion of the artery tends of itself, whether it be due to feebleness of the heart, high tension, or rigidity of the artery, to lessen the massage and to interfere both with the nutrition

of the vessels and with the onward passage of venous blood and lymph. On the other hand, if the alternate dilatation and contraction of the artery at each pulse be extensive, as in the lower tracing (Fig. 132), the self-massage will be well effected. Baths, exercises, general massage, and drugs, which increase the amplitude of the pulse, are therefore useful aids to the nutrition of the arteries. Digitalis and its congeners increase the amplitude of the pulse by strengthening and slowing the

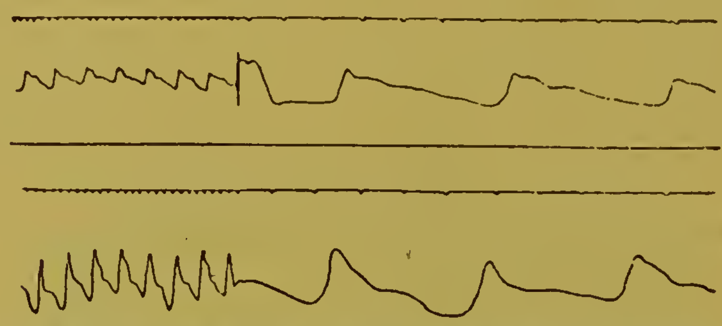


FIG. 132.—Pulse tracing, showing the effect of massage and graduated movements. Each tracing is taken partly with a slow and partly with a quick movement of the sphygmograph. The upper shows high tension and a feeble heart; the lower shows less tension and a stronger heart. These tracings I owe to the kindness of Dr Gustav Hamel, to whose treatment I had recommended the patient.

heart (p. 143); vascular dilators, like the nitrites, do so by diminishing the tension (p. 161).

Nervous Depression.—One of the causes of feeble pulse is feebleness of the heart's action, and this may be due to many causes. One common and important cause is nervous depression, which acts through the vagus nerve. (Fig. 133.) This nerve, which has received its name of vagus from its wandering course, and which the Germans have translated as "die herumschweifende Nerv," gives branches to the heart, lungs, stomach, intestines, liver, and kidneys.[1] As I have already mentioned in another paper, nearly all the emotions can be expressed in terms of this nerve. We say that the man's heart sinks within him for fear or apprehension, it beats high with joy or hope, he sighs for grief; the stomach is affected, and vomiting may ensue from disgust; the bowels move with compassion; and the effect upon the kidneys from simple excitement is well known to all

[1] The pneumogastric appears to exert its action on the last three organs through the cœliac, hepatic, and splenic plexuses.

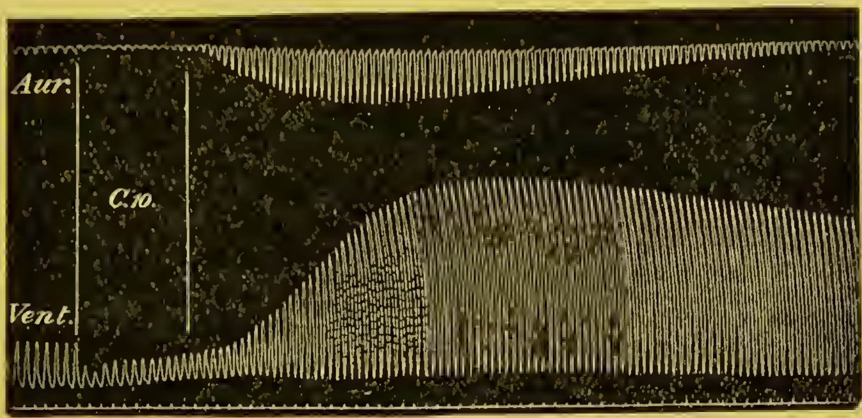


FIG. 133.—After Gaskell. Tracing showing diminished amplitude of contraction without slowing or stoppage during irritation of vagus.

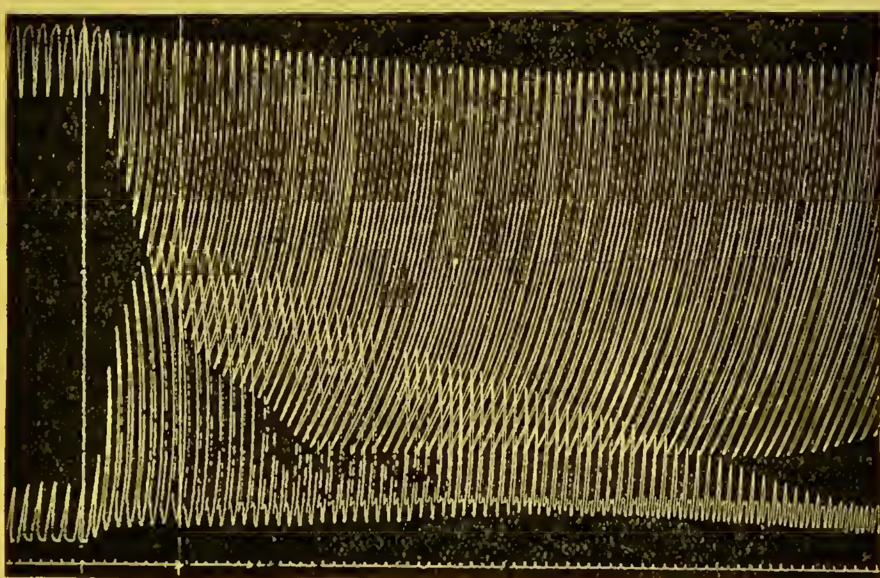


FIG. 134.—After Gaskell. Showing increased cardiac action from stimulation of the vagus. In this figure the lower tracing is that of the auricle and the upper that of the ventricle.

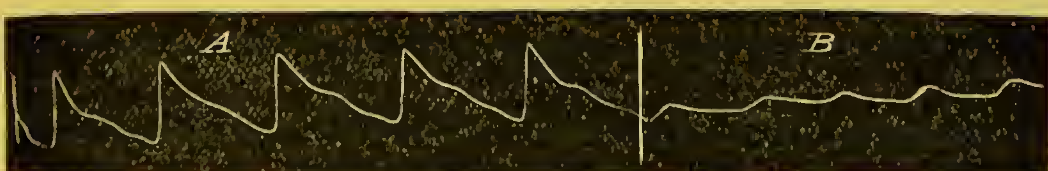


FIG. 135.—Showing the effect of cold upon the arteries. A shows the normal sphygmogram from the radial artery. B is the same after the application of a cold compress above the elbow. (After Winternitz.)

those who have had to do with examinations. Nervous depression from emotional causes is, I believe, a much more potent factor in disease of the circulation than is generally recognised. The effect of grief, worry, and anxiety upon the circulation, especially in elderly people, is sometimes very marked. Not long ago, I saw a man whose heart was very much diseased indeed, as shown by physical examination, but he displayed wonderfully few symptoms until he was told the actual condition of his circulation, when he seemed, to use a common expression, "to take it to heart," and from that moment he went down steadily and rapidly, and died within a few days. The coincidence was very marked, as the change in him occurred within a couple of hours, so that one could hardly ascribe it to anything else than nervous depression. Conversely, hope and joy are most potent factors in stimulating the cardiac action, and thus increasing the circulation throughout the body, and putting into action all those subsidiary aids to the nutrition of the vessels, and the return of venous blood and lymph, of which I have already spoken. (Fig. 134.)

One can plainly see that long-continued depression of the heart's action by grief may bring about a condition of malnutrition with no very definite organic change to explain it; and such a condition is indeed frequently noticed, not only in the old, but even in the young, where sometimes it produces a predisposition to tuberculosis. I have seen one girl who was really murdered by a curate, although no Court of Justice could have laid the crime at his door. He paid attentions to her, led her to believe that he was going to marry her, then suddenly forsook her and married another. Grief at this action depressed the circulation of the poor girl he had deserted, brought about a condition of malnutrition, she got phthisis, and died in less than a year.

It is possible that an abnormally low blood pressure may sometimes be a precursor of phthisis, and give early warning of danger. I have seen one case in which an abnormally low pressure was accidentally found in an apparently healthy man, who developed phthisis several months afterwards.

Fatty Degeneration.—Another very frequent cause of

weakened cardiac action is degeneration of the muscular structure itself, fibrous or fatty. This occurs very often in diphtheria, typhoid fever, and other infective diseases. It may also occur from altered nervous supply, and Eichhorst[1] observed fatty degeneration in the heart of fowls, and Wassilieff in that of rabbits,[2] after section of the vagi. Probably the great weakness of the heart after diphtheria is due in some cases to a double action, viz., (1) to the effect of the toxin in causing degeneration of the cardiac muscles, and (2) to its effect in producing paralysis of the vagus nerves, just as it does of the nerves going to the pharynx. This paralysis is shown by the extreme rapidity of the pulse, which may come on during the height of the disease and continue for months afterwards.

Fatty or fibrous degeneration of the muscular fibres naturally produces feeble action of the heart, and such degeneration is commonly consequent upon interference with the circulation through the coronary arteries. Here we must distinguish between the two sides of the heart, because although both coronary arteries may be affected, yet occasionally we find one affected and not the other. The symptoms due to affection of the two sides we shall have to consider later on.

Pulse-rate.—The rate of the heart, the rapidity or infrequency with which it beats, depends upon many factors. In healthy animals increased blood pressure slows the heart by its action upon the vagus roots, but when these nerves are divided increased pressure has a variable action on the heart; sometimes slowing it, sometimes quickening it, but the conditions upon which such retardation or acceleration depend have not yet been fully ascertained. Heat as a rule accelerates the pulse-rate and cold retards it, the effect of heat being to render the heart more excitable, so that (1) stimuli are generated more quickly in the venous sinus and auricles, and (2) also pass more quickly to the ventricle. The effect of cold on the isolated heart is exactly the opposite. Moreover, heat tends to dilate the vessels, and thus to lessen the resistance the heart has to

[1] Eichhorst, *Die trophischen Beziehungen der Nervi Vagi zum Herzmuskel*, Berlin, 1879, p. 18.

[2] Wassilieff, *Ztsch. f. klin. Med.*, 1881, iii., 316.

overcome, while cold has an opposite effect. The circulation in fevers, therefore, is usually rapid, and a warm room sometimes appears to cause such vascular dilatation that in delicate people faintness comes on and a tendency to syncope; the

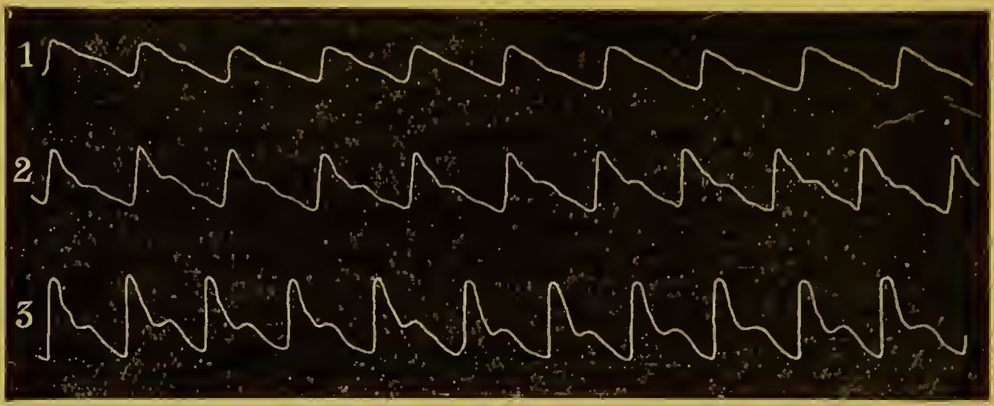


FIG. 136.—Shows the effect of warm clothing in dilating the arterioles, quickening the pulse, and reducing the high tension of 1 to the low tension of 3. (After Marey.)

dilatation probably occurring chiefly in the splanchnic area, in which the blood accumulates, as it does after section of the splanchnics. (*Cf.* Fig. 10, p. 12.)

The normal pulse-rate in men is from about 60 to 80 per minute. Its rate when the vagi are paralysed is about 120.

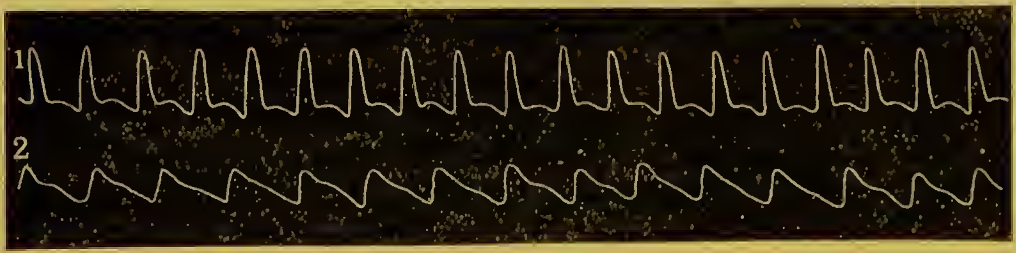


FIG. 137.—Effect of fever.

This is known from the fact that large doses of atropine or belladonna paralyse the vagus; and in cases of poisoning by these substances in man the pulse-rate has gone up to 120 or upwards.[1] In very nervous people, especially some women, the pulse-rate may rise a good deal above this, but such quickening is only temporary.

[1] Atropine probably stimulates the accelerators as well as paralyses the inhibitory nerves of the heart.

The pulse of 120 occurs very frequently as a temporary condition in fever, and may occur more or less permanently from paralysis of the vagi after diphtheria, or from alcoholic neuritis.

Exophthalmic Goitre.—In cases of exophthalmic goitre the internal secretion of the thyroid appears not only to quicken the heart but to dilate the vessels, and in this disease the pulse frequently rises to 130 or 140 beats per minute, or even more. It would thus appear that not only is the vagus paralysed, but that the accelerators are stimulated. That this effect upon the circulation is partly though not entirely due to the action of the actual secretion of the gland itself, is shown by the fact that thyroid, when taken by the mouth too frequently and too long, in cases of myxœdema, will produce these effects upon the circulation. (*Cf.* p. 180.)

LECTURE IV

Paroxysmal Tachycardia—Bradycardia—Intermittent Pulse—Palpitation—Shock—Syncope—Embolism and Thrombosis—Claudication—Angina Pectoris—Raynaud's Disease—Chilblains, Urticaria, Angia-neurotic Œdema—Migraine—Sensitiveness of Arteries—Sensitiveness of the Heart. VALVULAR DISEASES OF THE HEART: Aortic Obstruction—Aortic Regurgitation — Failing Compensation — Mitral Incompetence (Functional)—Cardiac Strain.

Paroxysmal Tachycardia.—There is a nervous affection of the heart known as paroxysmal tachycardia, in which the pulse suddenly becomes quick and continues so for a length of time, varying from minutes to hours, and then returns suddenly to the normal. It is usually accompanied by feelings of great discomfort, sometimes like those of angina pectoris. The cause of it is obscure. It is generally associated with some disease of the walls of the heart, especially with fatty degeneration.

Bradycardia.—Another condition, just the opposite of this, is extreme slowness of the heart, or bradycardia. In this condition the pulse may fall as low as eighteen per minute. Napoleon's pulse is said to have been only forty per minute during the whole of his life. The slow pulse may be either apparent or real. In some cases an apparent slowness is due to the fact that some beats of the heart are so feeble that the ventricle never opens the aortic valves, and no pulse reaches the wrist. Sometimes alternate beats are weak and strong, so that for a heart beating eighty times per minute only forty radial pulses are felt. (Fig. 138.) In other cases, however, there are no small beats but only slow pulsations. Weakness of the heart leading to this condition may occur from temporary feebleness after fevers, and especially infective fevers such as diphtheria, enteric,

pneumonia, and rheumatic fever, or from general debility, or from fatty or fibroid degeneration of the cardiac walls. It sometimes occurs when the resistance which the left ventricle has to overcome is very great, as in Bright's disease and lead poisoning. It also may happen from increased resistance to the action of the right ventricle in emphysema. It may be due to irritation of the vagus centre in the medulla, either by (1) central influence, or by (2) reflex stimulation of peripheral origin. Among the central causes are pressure upon the brain by tumour; by effusion of blood, as in apoplexy; by chronic inflammation, as in general paralysis; as well as in mental affec-

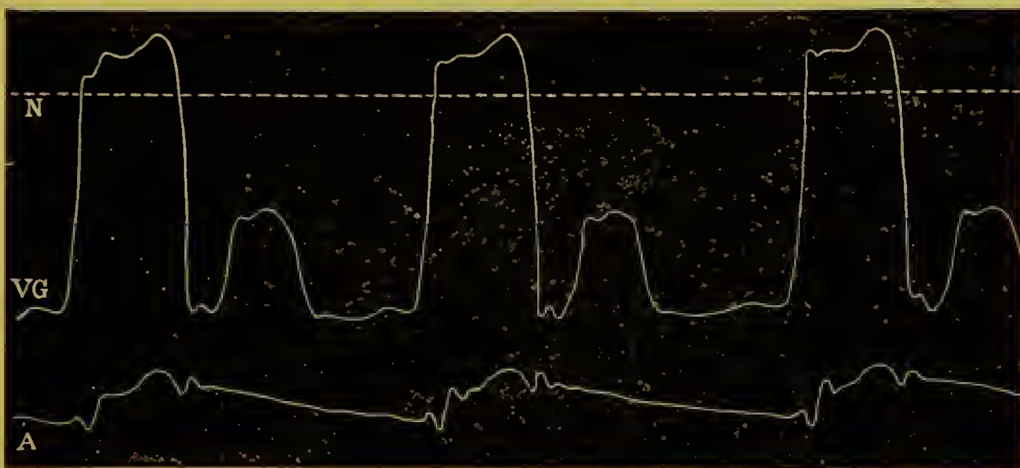


FIG. 138.—Tracings from the left ventricle and aorta, showing a slow pulse in the aorta due to each alternate beat of the ventricle being too weak to overcome the pressure within the aorta and lift the aortic valves. The upper tracing, V G, is from the left ventricle. The lower, A, is from the aorta. N is the level which the pressure within the ventricle must attain in order to raise the aortic valves. (After Marey.)

tions, mania, and melancholia, and disease or injuries of the medulla itself, and of the cervical cord. It may be brought about by reflex irritation from the sexual organs, from the skin, from the liver, or from the stomach, as in chronic dyspepsia, gastric ulcer, and cancer. (Fig. 139.) It occurs in poisoning by bile-acids, in jaundice, the action here being probably exerted on the muscular fibre. Other agents, such as tobacco, coffee, digitalis, and sometimes alcohol may cause it, partly by their action upon the cardiac muscle, and partly upon its nervous supply.

Intermittent Pulse.—Both in tachycardia and bradycardia, although the rate of the pulse is disturbed, its rhythm remains

regular. Intermission of the pulse is a frequent condition. In it one beat is occasionally dropped. This may happen once in three times, so that two regular beats come followed by a pause, or it may occur in four, five, or more beats which are quite regular, or it may happen at irregular intervals; for example, once after three, next time after five, next after seven, and then

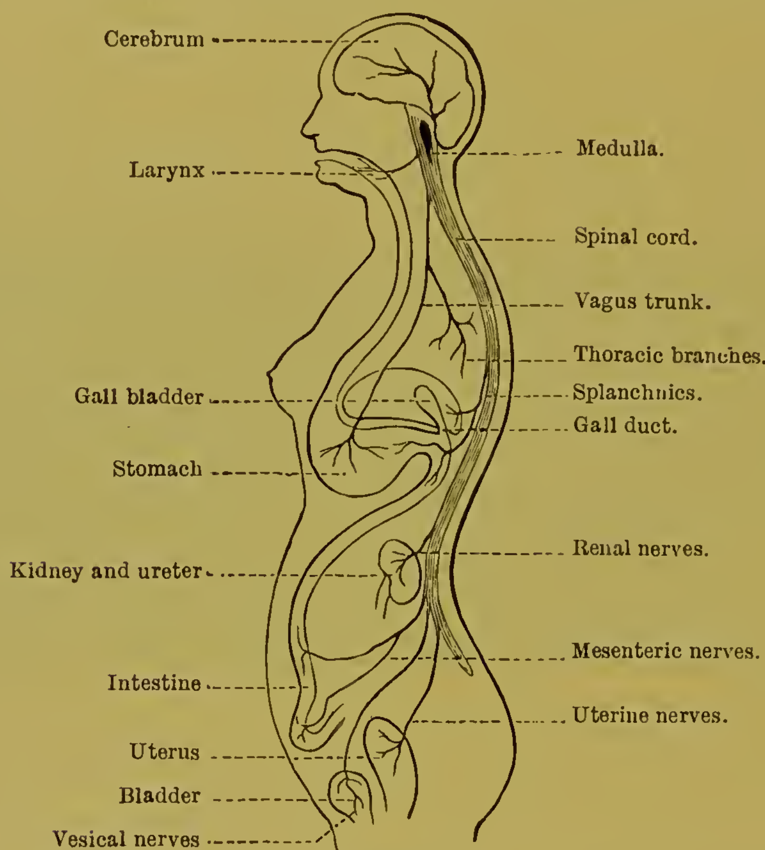


FIG. 139.—Diagram to show the afferent channels through which the vagus may be stimulated.

again after two. Such irregularity may possibly be a portion of a very large recurring rhythm, but in most cases if such a rhythm exists it is difficult or impossible to make it out. In the case of a man recovering from digitalis poisoning, I had occasion many years ago to observe the form of irregularity shown by the pulse.[1] At first the beats were very rapid with occasional slow ones interspersed, then it became slow with an occasional

[1] Lauder Brunton, "On Digitalis," etc., Inaugural Thesis, 1866. Reprinted in *Collected Papers on Circulation*, First Series, pp. 100 and 101.

rapid beat or two, and finally slow and regular. (Figs. 140 to 144.)

In poisoning by tobacco the irregularity is sometimes very extraordinary; one slow, strong beat followed by a number of very quick ones. This condition may also occur quite apart from tobacco, and may persist for many years without really affecting the patient's health. It is impossible to give, with certainty, any explanation at present of the exact cause of these

FIG. 140.—Pulse tracing from a case of poisoning by digitalis, showing quick pulse with slow beats interposed.

FIG. 141.—Same case.—Recovering from the effects of the poison, and showing slow pulse with occasional quick beats.

FIG. 142.—Same case.—Slow pulse, with beat interpolated at *b*.

FIG. 143.—Same case.—Pulse regular, but quickened by food.

FIG. 144.—Same case.—Recovering; pulse slow and regular.

forms of irregularity. Some of them, such as irregular bradycardia or occasional intermission of a beat, are explained by supposing that the conduction in the muscular fibres connecting the auricle and ventricle is less perfect than usual, so that a block occurs, as in Gaskell's experiments. The cases of tachycardia with an admixture of very rapid and slow beats, are less easy to explain, on the assumption that cardiac rhythm is entirely a function of its muscular fibres, and I am inclined to think that the true explanation can only be given on the

assumption that the nervous system also plays a part in the cardiac rhythm, and that sometimes the nervous and muscular rhythms interfere with one another. In my first lecture I mentioned some of my grounds for this belief, and since it was delivered, details of experiments by Von Basch and Fröhlich have been published, which tend to substantiate the accuracy of the views that I then brought forward.[1]

Palpitation.—Palpitation of the heart is a very troublesome symptom, and its causation is very obscure. Sometimes it appears to be almost a purely subjective sensation, as the patient has a sensation of the heart beating strongly, yet the hand applied to the apex beat does not perceive anything unusual. In other cases the force of the apex beat, as felt by the hand, is distinctly increased. I have noticed such an increase take place in animals poisoned by digitalis. In my thesis on the action of this drug, I discussed the mechanism of palpitation, and arrived at the conclusion that it was probably due to increased power of the heart in proportion to the resistance it had to overcome, so that the ventricular contraction occurred rapidly, and the apex therefore struck forcibly against the chest wall.[2] What seems to confirm this opinion is, I think, the fact that palpitation is frequent in states of debility, but that when the heart is hypertrophied and the tension is high, so that, despite its abnormal strength, the heart cannot contract quickly, palpitation is frequently, indeed one may say generally, absent.

Effect of Position on Palpitation.—One would naturally expect that a constantly recurring rhythmic blow upon the heart at each pulsation would increase its action, and, as a matter of fact, this appears to be the case. The heart is a mobile organ and moves considerably to the left when a person lies on that side. The apex, therefore, tends to strike more forcibly against the chest wall, and as the effect of this is similar to that of a blow on the heart at each beat, many people are

[1] Von Basch and A. Fröhlich, *Centralblätt f. Physiologie*, Bd. xviii.; *Literatur*, 1904, p. 693.

[2] Lauder Brunton, "On Digitalis," etc., *Collected Papers on Circulation and Respiration*, First Series, p. 52. London: Macmillan & Co.

unable to lie on the left side in consequence of the palpitation which then comes on.

Shock.—Another important condition in which both heart and vessels appear to be affected is that of shock. Here the heart may become slow and feeble, but this does not appear to be all, for the general depression is out of proportion even to the feebleness of the heart's action. Shock is especially apt to come on from a blow upon the abdomen, and Goltz in his famous experiment showed that if a frog be suspended in the upright position and its heart exposed, a blow upon the intestines has a twofold action. It (1) stops the heart reflexly through the vagus; but after this effect has passed off (2) the heart beats again, but is empty and sends on no blood into the vessels, because the blow has caused dilatation of the abdominal vessels, and all the blood becomes stored up in them, so that none reaches the heart. (Fig. 145). It is not improbable that a similar effect may occur from irritants inside the stomach or intestine, because when large quantities of alcohol have been swallowed at a draught, death has occurred almost instantly, and the mechanism of its production was probably the same as in Goltz's experiment. Severe pain from irritation of nerves in other parts of the body may stop the heart, but under ordinary circumstances it also causes contraction of the abdominal vessels, and thus keeps up the blood pressure and maintains the circulation. If the pain be very excessive, it is quite possible that an opposite effect may be produced, and thus fatal syncope may ensue.

FIG. 145.—Diagram to illustrate Goltz's experiments. *a*, normal heart in the upright position; *b*, heart in same position after shock; *c*, heart as in *b*, but in recumbent position, showing it full, so as to keep up circulation, though the veins are still dilated.

I think also that in surgical operations if anæsthesia is imperfect, reflex stoppage of the heart may occur without reflex contraction of the vessels, and thus fatal shock may be produced, whilst perfect anæsthesia would have abolished any reflex action on the heart as well as on the vessels, and thus prevented any danger.

Syncope.—The remarkable difference between shock and

syncope is that usually in shock the brain remains clear, but in syncope the person becomes suddenly unconscious. The pathology of syncope has not been thoroughly made out, but it appears to be due to sudden anæmia of the brain. The brain requires a large supply of blood when it is functionally active, so that blood is withdrawn from the limbs, and they become

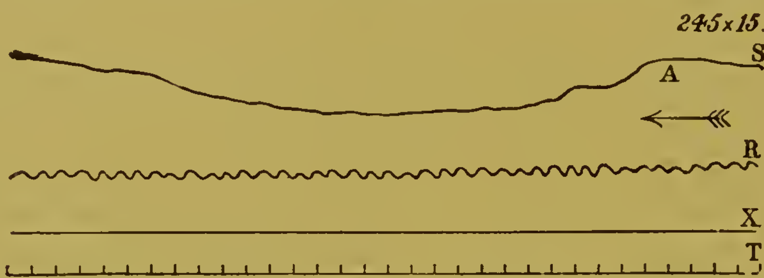


FIG. 146.—To show the contraction of the vessels produced during the process of multiplying 245 by 15. S, Volume of left arm. A marks the point at which the calculation was commenced; after this point the pressure falls. R, Respiratory movement of chest. X, Abscissa. T, Time line; every upright marks an interval of five seconds.

smaller. This is shown by Mosso with the aid of the plethysmograph (p. 67). When measured by this instrument, the volume of the arm was found to become much smaller when the person thought hard, as the blood required by the increased functional activity of the brain was withdrawn from the arm. (Fig. 146.) When the body is upright, the pressure of blood

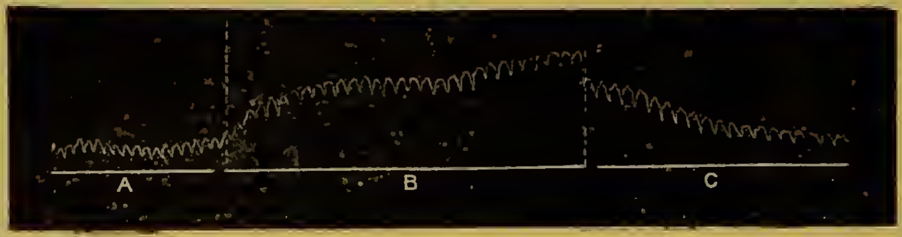


FIG. 147.—Tracing from the brain. A, in upright posture; B, with the head inclined forwards. (After Brissaud and François-Franck. Marey's *Travaux*, 1877.)

in the brain is less, but it becomes greater when the head is lowered. (Fig. 147.) The recumbent position is therefore the best to restore a fainting person, and the tendency to faint may sometimes be averted by placing the head on the hands between the knees. (Fig. 148.) Before the introduction of anæsthetics it was a frequent custom to perform operations in a state of syncope, which was induced by laying the patient

flat on the ground for a short time and then raising him very suddenly to the upright position by several strong men. A curious observation was made by John Hunter on the flow of blood during syncope. In a lady who was being bled, the blood issued from the vein slowly and was black, but the moment she fainted the blood rushed out quickly and became of a bright colour. This phenomenon is exactly what is seen in the condition of the submaxillary gland when its arterioles dilate on irritation of the chorda tympani. As the blood from the veins at the bend of the arm comes to a great extent through the muscles, we are, I think, justified in believing that, in some cases of syncope at least, the vessels of the muscles undergo sudden dilatation, and thus the blood pressure becomes enormously and instantly reduced.

Fig. 148.—Attitude to prevent fainting.

Embolism and Thrombosis.—When the blood-vessels become obliterated, the supply of blood to the parts to which they are distributed may become so insufficient that the tissues die and gangrene ensues. This obliteration may be due to embolism or thrombosis; as, for example, when a clot or vegetation becomes detached from the heart and is carried onwards by the circulation until it is stopped in an artery through which it cannot pass, and which it consequently plugs. Sometimes the arterial wall undergoes atheromatous degeneration, and this may either lead to thrombosis occurring at the spot where the wall is narrowed, or the atheromatous matter may become dislodged and produce embolism further on. In old persons, the arterial walls may become degenerated and contracted to such an extent that senile gangrene of the extremities appears. Before such a stage as this is reached, however, an inability for exertion comes on. This was noticed by Sir Benjamin Brodie, and his description is so good that I cannot do better than quote it:—

Claudication.—"Such patients," he said, "walk a short distance very well, but when they attempt more than this, the

muscles seem to be unequal to the task, and they can walk no further. The muscles are not absolutely paralysed, but in a stage approaching to it. The cause of all this is sufficiently obvious. The lower limbs require sometimes a larger and sometimes a smaller supply of blood. During exercise a larger supply is wanted on account of the increased action of the muscles; but, the arteries being ossified or obliterated, and thus incapable of dilatation, the increased supply cannot be obtained."

Angina Pectoris.—"This state of things is not peculiar to the lower limbs. Wherever muscular structures exist, the same cause will produce the same effect. Dr Jenner first, and Dr Parry, of Bath, afterwards, published observations which were supposed to prove that the disease which is usually called 'angina pectoris' depends on ossification of the coronary arteries. . . . When the coronary arteries are in this condition they may be capable of admitting a moderate supply of blood to the muscular structure of the heart; and as long as the patient makes no abnormal exertion, the circulation goes on well enough; when, however, the heart is excited to increased action, whether it be during a fit of passion, or in running, or walking upstairs or lifting weights, then the ossified arteries being incapable of expanding so as to let in the additional quantity of blood, which, under these circumstances, is required, its action stops and syncope ensues; and I say that this exactly corresponds to the sense of weakness and want of muscular power which exists in persons who have the arteries of the legs obstructed or ossified." [1]

Raynaud's Disease.—Temporary contraction of the artery and anæmia of the tissues occurs in a disease described by Raynaud, and which bears his name. In this disease the arteries contract spasmodically, and I have seen first of all the tips of the fingers become cold, bloodless, and shrunken like the fingers of a corpse, and this condition gradually extended up the hand in the course of five or ten minutes. Sometimes only one finger is affected, sometimes the whole hand, sometimes the toes, the tips of the ears or the nose, and occasionally, though

[1] *Lectures on Pathology and Surgery*, by Sir Benjamin Brodie, London, 1846, p. 360.

rarely, the arms and legs. The internal arteries appear also to undergo a similar contraction, especially those of the kidneys and brain, because this disease is frequently associated with hæmoglobinuria and sometimes with epileptic symptoms and transient hemiplegia. The condition is very much like what occurs after immersion of a hand in very cold water, and just as after the hand has been withdrawn it usually becomes swollen hot and red, so the extremities after the spasm has passed off in Raynaud's disease become red and hot. In very cold days we notice that the whiteness of the skin which indicates both arterial and venous contraction, is succeeded by arterial contraction with venous dilatation, so that the surface becomes blue instead of white. The same thing occurs in the severer cases of Raynaud's disease, and the term of local asphyxia has been given to the condition. In extremely severe cases the contraction has led to complete stoppage of the blood supply, and consequent gangrene, like that which occurs in senile degeneration of the vessels.

Chilblains, Urticaria, Angio-neurotic Œdema.—A condition which is very much allied to this, but much milder, is the common one of chilblains. Another ailment which is very troublesome and where there is a local vascular dilatation with effusion of lymph, is urticaria. The wheals characteristic of this complaint are very much like those which are produced by a stinging nettle. They may occur without visible cause, but in some persons with an irritable vascular system they may be produced by simply scratching the skin, so that the patient's name may be written on his back with the finger-nail. In so-called angio-neurotic œdema, instead of mere wheals occurring, the patient may become affected by rapid and intense œdema over a large portion of the body. I have seen in half an hour one side of the patient's face become so much swelled that the left eye was almost closed, and the left side of the face was like that of a patient suffering from advanced renal dropsy, whilst the other side of the face remained perfectly healthy. The pathology of this condition has not been made out, but the cause of the trouble probably is that there are toxic substances in the blood, for urticarial rashes are very

common after the injection of diphtheria antitoxin, and I have seen universal œdema, resembling that of advanced renal dropsy, brought on by the injection of anti-streptococcic serum. The one-sided character of the affection in the case I have just mentioned shows that the nervous system is also deeply concerned in the disease.

Migraine.—Sensitiveness of Arteries.—In the conditions of which I have just been speaking the small arterioles and capillaries are chiefly affected, but arteries of moderate size, such as the temporal artery, and even large arteries like the

FIG. 149.—Diagram of the carotid, temporal, and occipital arteries in the normal state.

FIG. 150.—Diagram of arteries during migraine, showing dilatation of the carotid and spasmodic contractions of the temporal arteries.

carotid, may undergo very considerable alterations in their calibre, either in the way of contraction or dilatation. A good deal of discussion has taken place in regard to the pathology of sick headache or migraine. Du Bois Reymond described the temporal artery in his own case as being much contracted during the headache, and therefore concluded this was a general condition; while others have described this artery as widely dilated and throbbing, and have supposed this condition to be constant. I have unfortunately had only too many opportunities of repeating these observations on my own head, and I have found that, as is often the case, both parties are right and

both parties are wrong; that the condition described by each occurs, but that it does not extend to all parts of the artery at the same time. Sometimes, for example, during a fit of migraine I have found my temporal artery widely dilated and throbbing (Fig. 151), at other times I have found it hard and contracted, like a piece of whip cord (Fig. 150); but when it was dilated, if I followed it onward towards the periphery I ascertained that the ascending temporal branch was contracted like a bit of piano wire. (Fig. 151.) On most occasions, if I followed the contracted temporal artery backwards towards the heart, I found that the carotid on that side appeared to be as thick as my thumb, distended to three times its normal diameter, and pulsating violently. The conclusion I came to, therefore, in regard to the pathology of migraine, is that there is *peripheral contraction and central dilatation* of the arteries. Arteries are sensitive, as was known in the old days before the introduction of anæsthetics, because patients complained of pain when the arteries were ligatured. That the pain in migraine is to a great extent due to the stretching action exerted on the contracted temporal artery by the blood which tries to pour into it from the dilated carotid, is shown by the fact that if pressure be exerted upon the carotid so as to stop the pulse in the temporal artery, the headache will frequently disappear instantly. Unfortunately, however, it is almost impossible to compress the carotid without also pressing upon the vagus, and the sense of oppression on the chest which this produces is so great that one is generally obliged to stop the compression after a few seconds, although the moment the finger is removed the pain in the head comes back with a rush of peculiar intensity. Megrim is often regarded as a neuralgic condition,

FIG. 151.—Diagram of arteries during migraine, showing dilatation of the carotid and temporal arteries, and spasmodic contraction of the ascending frontal branch of the anterior temporal artery.

but the observations upon my own head which I have just detailed have convinced me that, although the vascular disturbance which occurs in it is almost certainly due to an altered action of the vaso-motor nerves, yet the pain is to a great extent like that of colic, where we find intense pain due to spasmodic contraction of one part of the intestine with dilatation or distension of another.

Sensitiveness of the Heart.—Like the vessels, the heart is probably sensitive and capable of originating pain of a most intense character. Pressure from the outside is not felt, as Harvey discovered in the case of young Lord Montgomery, in whom a congenital defect of the sternum exposed the heart. But pressure from without, unless very excessive, does not produce pain in hollow muscular organs such as the stomach, intestines, urinary bladder, gall-bladder, gall-duct, or ureter, yet distension from within causes pain of the most intense character in all of those organs. All these are liable to discomfort without pain, and the heart, too, frequently feels discomfort without pain. The sense of oppression which is felt from grief or anxiety is, I think, due to the effect of the vagus nerve, because I have noticed in my own case that grief has produced a sensation of oppression in the chest which has persisted after the emotion which had given rise to it had passed away. We know that this feeling of oppression can be produced by mechanical irritation of the vagus; for Professor Czermak had a small exostosis on one of his cervical vertebræ, and by compressing his vagus between it and his finger he was able to stop his heart, but the pressure at the same time caused this feeling of oppression, or, as he termed it, "Beklemmung" in the chest.[1]

In angina pectoris there are frequently two sensations, or perhaps even more: one of intense oppression, and one of extreme pain. That of extreme pain I am inclined to regard

[1] When Professor Czermak described this feeling he supposed that the vagus was compressed between his finger and an enlarged gland, but I was informed by the late Professor Sharpey that what Czermak supposed to be a gland was afterwards discovered to be an exostosis on one of the cervical vertebræ.

as similar to colic in the intestine, and as depending upon spasmodic contraction of the heart against resistance which it cannot properly overcome. It is very difficult to make observations in angina pectoris; because when the attack comes on, the apparatus for observation is generally not at hand, and even if it is, one is so much taken up with trying to relieve the patient that one does not care to trouble him with the application of instruments. In 1866 and 1867 I had an opportunity of making observations in a case of angina pectoris, in which the attacks occurred every night and lasted two or three hours. During the attack the pulse was very rapid and the arterioles were contracted, as is shown by the very slow fall of the arterial tension during the cardiac diastole. But even with everything at hand I only once succeeded in making one observation, and that a very imperfect one, of the commencement of an attack, which showed that as the pain came on the tension rose. (Fig. 212, p. 187.) I was able to make numerous observations regarding the end of an attack, and found that as the tension fell the pain disappeared.[1]

Valvular Diseases of the Heart

Aortic Obstruction.—We may now pass on to an important class of cases, namely, those of valvular disease of the heart. The aortic orifice sometimes becomes inflamed during fœtal life, and becomes narrowed in consequence, but more usually the aortic valves become either stiff with advancing years, or vegetations, frequently calcareous, form on them and lessen the diameter of the orifice.

We must distinguish carefully between "stenosis" and mere "obstruction," because a small atheromatous mass may obstruct the orifice and give rise to a loud systolic murmur, but yet may practically have little or no effect in lessening the lumen of the

[1] Since these lectures were delivered I have had an opportunity of watching a case of severe angina pectoris daily for many weeks, and have been able to satisfy myself that although rise of tension, quick pulse, and cardiac pain usually came on together, yet each might occur separately without the others. A feeling of anxiety often accompanied the pain, but anxiety might occur without pain, and *vice versa*.

vessel, and consequently will produce no practical change in the circulation or in the condition of the pulse. In many cases, especially of elderly people, the aorta becomes atheromatous and rough, so that a systolic murmur occurs in it, but unless the valves are affected, no regurgitation results. (Fig. 152.)

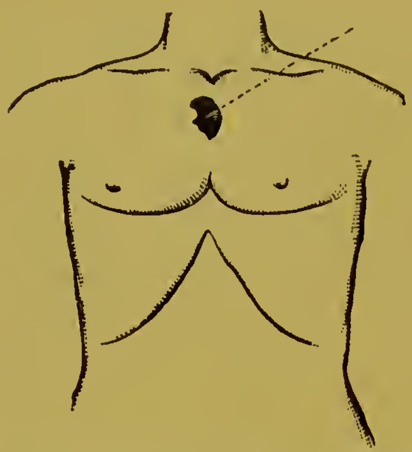


FIG. 152.—Diagram to show the usual position of the murmur which indicates atheroma of the aorta. It is generally heard best over the right half of the sternum, opposite the second rib or first intercostal space, but it may be lower down or higher up. It is sometimes very limited, but is frequently transmitted upwards along the innominate, while an anæmic murmur is transmitted usually horizontally to the left.

Aortic Regurgitation.—When the valves are diseased, general incompetency as well as obstruction occurs, and during the diastole blood flows back into the ventricle as well as onwards towards the periphery. (Fig. 155.) Slight degrees of pure stenosis have little or no effect upon the circulation, but as the work which the ventricle has to do in order to expel the blood is increased by the resistance in front, it usually becomes hypertrophied. As the amount of blood it has to send into the aorta is not more than usual, its cavity does not increase, or, in other words, does not undergo dilatation. When there is regurgitation as well as stenosis, blood pours into the ventricle from both ends, from the auricle and from the aorta, so that the amount of blood it is called upon to hold is greater than usual. Its cavity becomes dilated, and at the same time, in order to send this large wave of blood onwards, its walls require to be stronger than usual.[1] They become thicker, or, in other words, both dilatation and hypertrophy occur. So long as this compensatory hypertrophy is sufficient to enable the ventricle to do its work, there may be no symptoms at all, and I have seen patients engaged in arduous physical labour, carrying heavy hods of bricks up ladders many times a day, without knowing that there was anything the matter with them. Not infrequently one may notice that the face has a peculiarly

[1] For pulse tracing of aortic regurgitation, *vide* Fig. 115, p. 88.

pale, waxy look, and the arteries show a peculiar irritability and tendency to rhythmical contraction which, as I mentioned in my

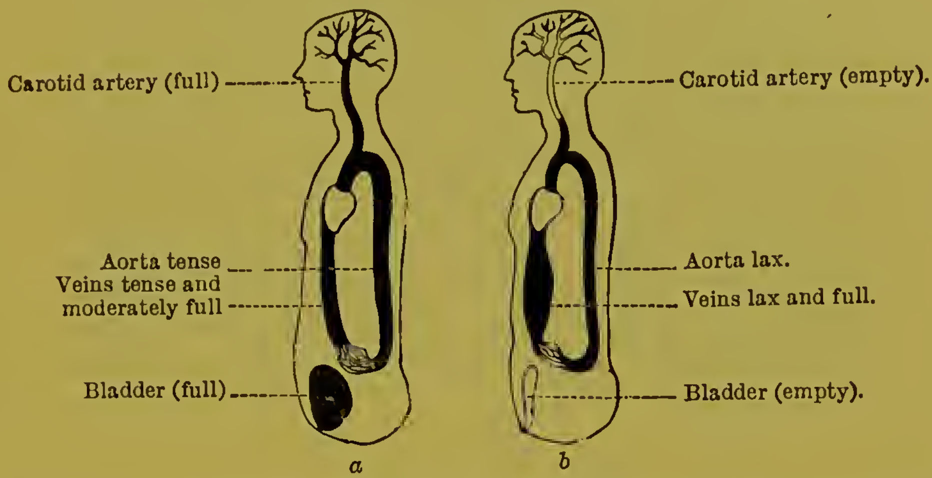


FIG. 153.—Diagram to illustrate the tendency to syncope in aortic regurgitation. In *a* the aortic valves are healthy and prevent regurgitation. The carotid and its branches are shown as full. In *b* there is aortic regurgitation, the blood flows out of the arterial system through the capillaries and into the heart. The carotid and its branches are shown as empty. In c the condition is the same as in *b*, but the patient is supposed to be in the recumbent posture, and the carotid and its branches remain full.

previous lecture, may be easily demonstrated by drawing the finger across the forehead.

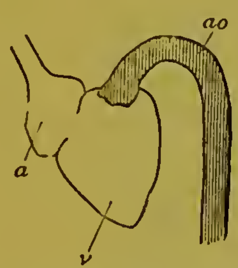


FIG. 154.—Diagram of healthy heart in diastole. The aorta is full of blood under pressure, as indicated by the shading, but the ventricle and auricle are protected from pressure by the sigmoid valves.

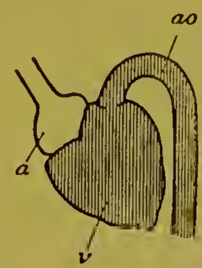


FIG. 155.—Diagram of a heart with incompetent aortic valves. The ventricle as well as the aorta is under pressure during diastole, but the auricle is protected by the auriculo-ventricular valves.

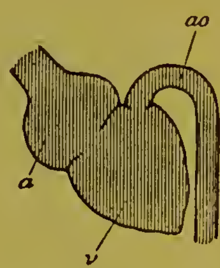


FIG. 156.—Diagram of a heart with incompetent aortic and mitral valves. The auricle and veins, as well as the ventricle and aorta, are under pressure constantly.

Failing Compensation.—But the enlarged heart requires an extra supply of blood, and the coronary arteries may by and by become insufficient to supply this, and then commencing cardiac failure sets in. When this is the case, symptoms of defective supply of blood to the brain occur (Fig. 10), such as giddiness, tendency to faint, or actual fainting; and symptoms

also referable to the heart, such as palpitation, cardiac uneasiness, or anginal pain.

Mitral Incompetence (*Functional*).—So long as the mitral valves remain competent, the symptoms remain limited to those parts of the body supplied by the aorta. But when the heart dilates so far that the mitral valves no longer close the auriculo-ventricular orifice and the blood pours back into the left auricle and pulmonary veins, symptoms of pulmonary engorgement develop.

Incompetency of the mitral valves may be brought about either by the orifice becoming too large for the valves, or the valves too small for the orifice. It was shown by Ludwig that, when the ventricle contracts normally, the muscular fibres around the auriculo-ventricular orifice lessen it to such an extent that even imperfect valves might close it; but when the heart is dilated, the orifice becomes so large that the valves will not close it, however healthy they may be.

Cardiac Strain.—Such dilatation occurs as a sequence to aortic regurgitation, but it also occurs from violent strain in healthy people (Fig. 158), and also from cardiac weakness. Indeed this happens not infrequently in cases of anæmia and debility, such as occur after acute disease. We then find that a systolic murmur, indicative of mitral regurgitation, becomes very evident, but as the heart gains power, the murmur completely disappears. One such murmur I watched with great interest in a girl, who was able to play lawn tennis without any injury whatever, but every time that she went to a dance, the combination of late hours and emotional excitement with active exercise brought on a marked systolic murmur.

Regurgitation may also occur from irregular action of the musculi papillaries, as I observed in some experiments which I made during the year 1865 upon the action of digitalis, and where I heard a mitral regurgitant murmur occur in the heart of a dog which had been poisoned by digitalis, although post-mortem examination showed the heart to be perfectly healthy.[1]

[1] Lauder Brunton, *Collected Papers on Circulation and Respiration*, p. 114.

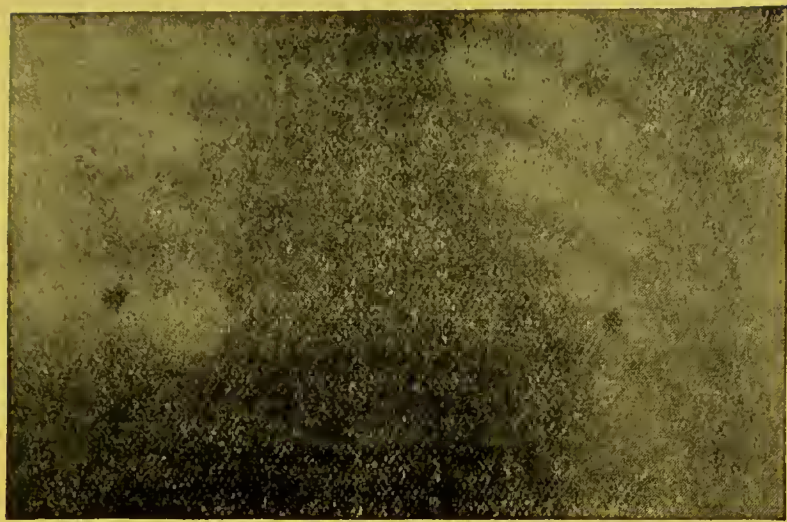


Fig. 157.—After Dr Th. Schott. Photograph by the Röntgen rays, showing the heart in a healthy man before exertion.

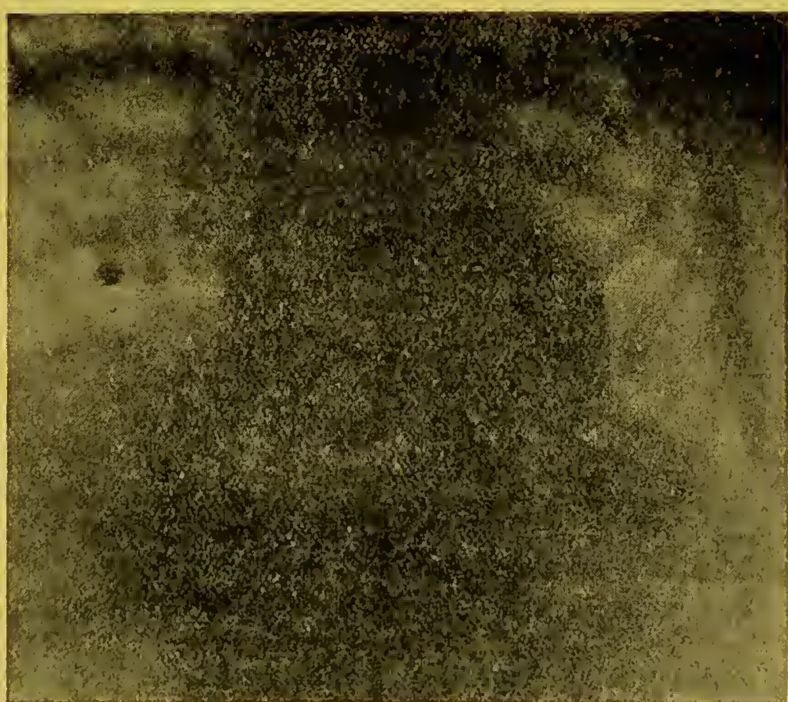


Fig. 158.—After Dr Th. Schott. Skiagram of the heart of the same man as Fig. 157, after violent exertion, showing temporary dilatation.

Roy and Adami have also described a similar condition. When the mitral valves become incompetent, the reflux of blood at each beat of a powerful ventricle tends to distend the auricle and the pulmonary veins from which the normal stimulus to ventricular contraction ought to start, and in consequence of this the cardiac rhythm is apt to be disturbed, and an irregular pulse will result. For this reason the irregularity of the pulse is more frequent in mitral than in any other form of cardiac disease.

LECTURE V

Mitral Regurgitation (Organic)—Mitral Obstruction—Cardiac Dyspnœa—Venous Engorgement—Other forms of Cardiac Disease—Vicious Circle. METHODS OF TREATMENT IN CARDIAC DISEASE: Uses of Treatment—Rest—Position—Use of Massage—Effect of Flatulence on the Heart—Use of Drugs in Cardiac Disease—Cardiac Nutrients—Digitalis and its Congeners—Action of Cardiac Tonics on the Embryonic Heart—Relation of this Action to Oxidation—*Résumé* of the Action of Digitalis.

Mitral Regurgitation (*Organic*).—Incompetence of the mitral valves occurs from distortion of the valves by inflammation, or by vegetations on their surfaces which prevent them from closing, even more frequently than from dilatation of the auriculo-ventricular orifice. The result, however, is the same. Whenever the valves are incompetent the ventricle drives the blood at each systole back into the auricle and pulmonary veins, as well as forward into the aorta, and during systole the pressure in the auricle and in the pulmonary veins must be nearly, if not quite so high, as that in the aorta. In consequence of this, the auricle becomes hypertrophied. As there are no valves in the pulmonary veins, it seems extraordinary that the pulmonary vessels do not suffer more than they do, and it appears to me not improbable that the contractile power of the pulmonary veins, which Sir Joseph Fayrer and I rediscovered,[1] may take the strain off the capillaries in the lungs, and thus prevent, to some extent, the tremendous congestion that might otherwise take place.

Mitral Obstruction.—When the mitral valves are much inflamed, they not unfrequently become adherent to one another, and the mitral orifice is thus so much narrowed that sometimes it will hardly admit the point of the finger. Great hypertrophy

[1] *Cf.* p. 17.

of the auricle then occurs, while the ventricle may be smaller than normal. In such a condition the pressure within the pulmonary veins and the auricle tends to be more or less constantly high, while that in the ventricle becomes low after the systole is over.

I mentioned before, when speaking of the physiology of the heart, that dilatation of the apex of the frog's heart by pressure from within would act as a stimulus to this portion of the ventricle, and cause it to beat rhythmically when it would otherwise remain perfectly still. The application of this constant pressure to the pulmonary veins and left auricle, while it is absent from the left ventricle, naturally tends to disturb the

FIG. 159.—Tracing of pulse from a case of mitral incompetence. (After Marey.)

rhythm, and consequently irregularity of the pulse is more frequent in mitral obstruction than in any other form of cardiac disease.[1]

Cardiac Dyspnœa. — Involuntary muscular fibre seems to have less power of withstanding strain when it is constant than when it is intermittent, and it is in mitral obstruction that we most frequently find the pulmonary capillaries giving way before the strain, and hæmoptysis occurring.

Backward pressure in the pulmonary circulation, of course, retards circulation through the lungs; less blood can pass through in a given time, and consequently both in mitral

[1] Luchsinger (*Arch. f. d. ges. Physiol.*, xxvi., p. 451, 1881) and Schiff (*Ibid.*, xxvi., p. 456) found that the rhythmical contraction in veins observed by Wharton Jones (*Phil. Trans.*, 1852, p. 1) depend on the pressure inside the veins; being well marked when the pressure is high, and absent when the pressure is low. *Cf.* p. 17, observations of Brunton and Fayrer on "Rhythmical Pulsation of the Vena Cava and Pulmonary Veins"; for if this observation holds good for these veins, the pressure may excite stimuli in the pulmonary veins whose rhythm may still further interfere with that of the other cavities of the heart.

regurgitation and in mitral obstruction, shortness of breath is a prominent symptom. A patient may be perfectly comfortable while at rest, but there is no reserve power, and exertion at once brings on quickened breathing and distress, which may sometimes be very severe. In consequence of this obstruction to the pulmonary circulation, the right ventricle has more resistance to overcome, it is obliged to contract with more force, and on account of the increased work tends to become hypertrophied. As a rule, its working power becomes more and more taxed until the maximum is reached, and then it begins to dilate, so that the tricuspid valves become incompetent and the blood pours back into the auricle and the venæ cavæ.

Venous Engorgement.—Dilatation and hypertrophy of the auricle occur in the same way as on the left side, but there being no valves in the venæ cavæ, the whole venous system is likely to become engorged. The first indication of venous engorgement is shown in those parts of the body where the venous pressure is highest, namely, in the feet and ankles, because in these places there is not only the backward pressure which exists in the vena cava itself, but the weight of the column of blood between the feet and the heart. It is this extra weight that determines the yielding of the venous capillaries and the exudation of fluid. This is shown by the fact that when the weight of blood is taken off the feet by keeping them raised upon a high stool or chair during the day, or by putting the patient to bed, the œdema as a rule disappears. Next the liver and portal system suffer. The liver becomes congested and enlarged, and flatulence both in the stomach and intestine becomes a troublesome symptom. (Figs. 14 and 181.) As the congestion increases the liver may be felt hard, smooth, and large, reaching down sometimes to the iliac crest, and water exudes into the abdominal cavity, producing ascites. The kidneys also become congested. The increased venous pressure lessens the circulation through the glomeruli, the urine becomes scanty and loaded with lithates, and then albuminuria appears. (*Cf.* Fig. 178, p. 149.)

Other forms of Cardiac Disease.—It is obvious that all the conditions I have just described may result as consequences of aortic regurgitation, but the number of these conditions will be

greater or less in other forms of cardiac disease, according to the point in the circulation where the lesion occurs. Thus, we may have all the symptoms of venous engorgement from weakness of the right ventricle and inability to drive the blood through the lungs. This weakness may be absolute, due to fatty degeneration of the cardiac muscle, consequent upon atheroma of the right pulmonary artery; or it may be relative, due to greater resistance to the circulation in the lungs themselves, as, for example, in chronic bronchitis and emphysema. A very instructive experiment in regard to this is that which goes by the name of Valsalva. If one breathes out against resistance—as, for example, by closing the mouth and nostrils forcibly, or, what is even more instructive, by blowing against the mercurial column in a manometer—it is found that the pulse will stop entirely when the pressure within the lungs reaches a certain point. As a young man I have frequently tried this, and could stop my pulse completely. So far as I can recollect, the height to which I raised the mercury before this occurred was somewhere between six and eight inches, but I have not repeated the experiment for a long time, and do not care to do so now, because it is not altogether without risk. In efforts of coughing, expiration is, of course, made against raised pressure caused by the closure of the false vocal cords,[1] which yield in an explosive manner after the pressure has become raised to a certain extent, and mucus is carried out by the forcible stream of air issuing from the lungs. In violent coughing, the effect of raised pressure in the pulmonary alveoli upon the pulmonary circulation becomes very evident. The face becomes congested, and if the coughing be long continued, becomes more or less livid, and the jugular veins stand out largely upon the neck. In people who are otherwise healthy, the ventricle recovers itself when the coughing ceases, but prolonged strain, as in chronic bronchitis or spasmodic asthma, tends to cause permanent dilatation of the right side of the heart with all its attendant evils.

Vicious Circle.—As in many other things, the conditions in cardiac disease form a vicious circle. The disordered circula-

[1] Brunton and Cash, *Journ. of Anat. and Physiol.*, vol. xvii., 1882-83.

tion disturbs the functions of other organs, and these in turn make the circulation worse. The condition, indeed, reminds one of Shakespeare's lines in regard to sorrow:—

> "Sorrow's weight doth heavier grow
> Through debt that bankrupt sleep doth sorrow owe."

The disordered circulation interferes with the functions of the lungs, liver, stomach, intestines, and kidneys. On account of the difficulty of breathing, exercise becomes impossible, and thus all the accessory aids to circulation given by the muscles and fasciæ during movement[1] are done away with. Appetite becomes lessened and flatulence increases; the elimination of waste products by the kidneys is interfered with, and distension of the abdomen, either by flatulence alone or by flatulence with ascites, presses the diaphragm up, encroaches upon the breathing space in the lungs, and tilts the heart up, thus still further increasing its difficulties. In such cases it is evident that the patient is bound to die, and to die a somewhat painful death, unless medical art can afford him assistance. It is very fortunate, however, that in such cases medical art can do so much.

Methods of Treatment in Cardiac Disease

Uses of Treatment.—Rest.—There is perhaps no kind of disease in which the results of treatment are so striking and so encouraging as in cardiac disease. If we can break the vicious circle at one point, we allow recovery to commence; and one of the most important agents—I think I ought to say *the most important agent*—in the physician's power *is absolute rest.* It is very hard indeed to make patients understand what one means by absolute rest. They are inclined sometimes to take the expression as meaning that they shall stay in the house, but that they may go up and down stairs as often and as quickly as they please. Now, few people have any idea of the amount of work involved in going upstairs. The weight of the body is so evenly distributed upon the muscles of the legs that we hardly feel the exertion in health, but if we suppose that

[1] *Vide* pp. 6 and 7.

we had fixed upon the bannisters of the stairs on the bedroom floor a strong pulley provided with rope and basket, and that the patient weighing, let us say, 150 lbs., is put into the basket on the ground floor, and that we had to pull him up by means of the rope, we will then understand the number of foot-pounds involved in the amount of exertion required to bring him from the dining-room floor to his bedroom. The weight is the same and the height is the same when the patient is drawn up in a basket and when he walks up himself. By putting the position before a patient in this way I have sometimes succeeded in convincing him that the work involved in walking upstairs was really great, and more than his enfeebled heart could stand. But it is not merely in walking upstairs that the heart has extra work to do. Even in getting into bed, work requires to be done, and, unfortunately, as in the case of a patient whom I saw immediately after giving my third lecture here, the exertion of getting into bed may prove fatal.

Rule regarding Rest for Patients.—The advice I give to patients is, that they shall *not take one beat out of their heart that can possibly be avoided;* that they shall not do one thing for themselves which anybody else can do for them. Nobody else can breathe for them, nobody else can swallow for them, nobody can evacuate for them; but with these exceptions everything else should be done for them. When they wish to sit up in bed, they should be raised up by others; when they wish to turn, others should move them; when they wish to evacuate, a bed-pan should be placed under them. There are certain people who seem to be unable to evacuate either the rectum or bladder in the recumbent position, and for these I am accustomed to recommend that a platform should be made of rough deal, of such a height as to raise a commode to the level of the bed, and that the patient should be slewed on to it and off it in such a manner that the pelvis always remains in the same plane, and is never either raised or lowered, the only change being in the relative position of the trunk and limbs.

Position.—But here we are met at once with the great objection that in these severe cases the patient cannot lie down on account of difficulty in breathing. The cause of this

difficulty of breathing while in the recumbent position is probably of twofold origin. In the first place, when the patient is supine, the contraction of the diaphragm at each inspiration has to raise the abdominal viscera (Fig. 160), while in the upright position it has only to push them horizontally forward. (Fig. 161.) Another cause, as Leonard Hill has pointed out, is probably the extra tension in the right side of the heart, which occurs when the heart is brought down to a level with the splanchnic area, and the comparative ease which occurs in the upright position is due to the blood remaining in the abdomen and limbs, so that the tension in the right side of the heart becomes less (*cf.* Figs. 10 and 145).

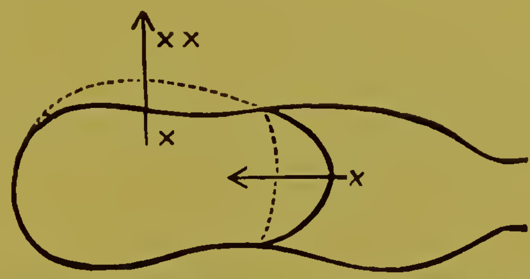


Fig. 160.—To show the lifting of the abdominal contents during inspiration in the supine position.

In some cases the facts that when the legs are raised, the venous tension in the cava becomes somewhat greater than when they are dependent, and also that when the thighs are swollen there is a little extra pressure exerted on the abdomen, make it necessary that the patient should be allowed to sit and not be confined to bed. But if he is sitting, he should be kept always in the same position; he should not get up at all, and he should have not an ordinary chair but a night-stool, so that the evacuations may be removed without disturbing him. Various beds have been devised upon which patients can lie comfortably and have their bodies and limbs placed at any angle that is desired without any exertion whatever on the part of the patient; but although these are theoretically very useful, they are not so much used in practice as I think they might be.

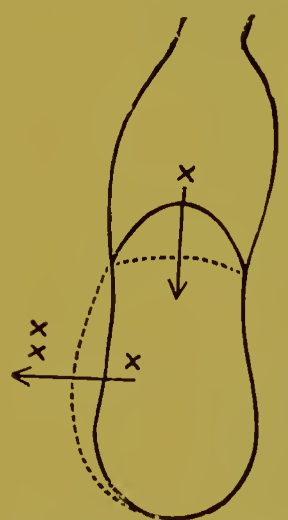


Fig. 161.—Diagram to show the horizontal motion of the abdominal contents in the upright position.

Use of Massage.—It is evident that when the patient is

resting completely, either in bed or in a chair, all the accessory means of circulation in the limbs of which I have already spoken are absent, and not unfrequently one finds that the feeble circulation in the muscles, and the consequent accumulation of waste products, give rise to feelings of heaviness in the limbs, discomfort, and restlessness which are very trying to the patient. In health, the arteries which run in the same sheath as the nerves exercise a kind of massage upon them by

FIG. 162.—Diagram of artery and nerve in a sheath of connective tissue, to illustrate self-massage of the artery and nerves. A, lymphatics. B, sheath. C, nerve.

the alternate contraction and expansion in the same way as on the veins (Fig. 162), but when the pulse is feeble the nerves suffer in consequence.[1] The indication for treatment here is to replace the natural accessories to circulation as far as possible by artificial ones, and this we are able to do to a certain extent by skilful massage. Massage is one of the most powerful agents in the treatment of such cases. It is a therapeutic agent of very great power and value; but, like opium, which from its utility has been termed God's greatest gift to man, it is liable

[1] *Vide* p. 6.

to abuse, and on account of its abuse it is often looked upon askance. But just as we cannot afford to throw opium aside as a medicine because it is liable to abuse, so we must employ

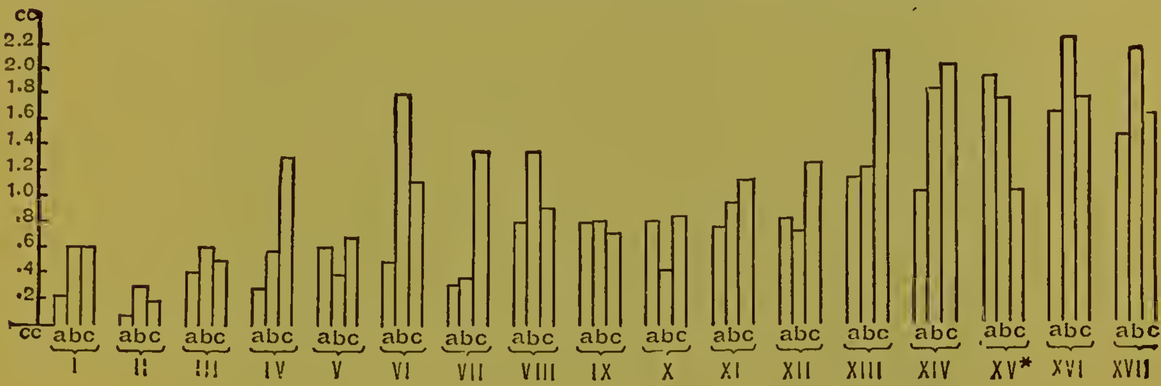


Fig. 163.—Diagram to show the effect of massage on the flow of blood through muscle. a. Shows the amount of blood in cubic centimetres which flowed from a muscular vein when it was simply opened. b. During massage. c. After massage. In VI. the rate of flow was increased threefold. Brunton and Tunnicliffe.

massage if we are to do the best for our patients, and at the same time we must guard, as far as possible, against any chance of abuse. By slow, firm, upward strokes along the

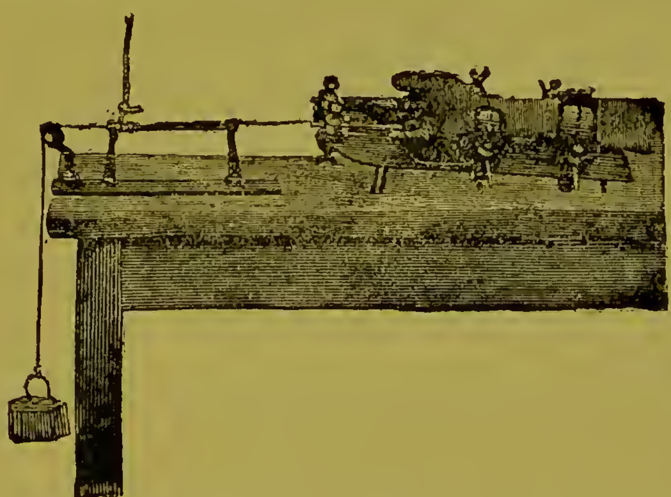


Fig. 164.—Mosso's ergograph. It consists of a clamping apparatus in which the arm is firmly held; a weight suspended by a string which runs over a pulley, and ends in a loop, into which one finger is put. In the middle of the string a small point is fixed which works upon a revolving cylinder covered with soot, so that each mark of the tracer can be distinctly seen. The finger is then contracted so as to raise the weight at intervals of two seconds. The amount of contraction is shown by the height of the up stroke, and as the exercise goes on the contraction becomes shorter and shorter, till at last exhaustion becomes complete.

legs and arms the venous blood is forced onwards towards the heart, and the fluid which has accumulated in the intercellular tissue is driven on into the lymphatics. Thus the

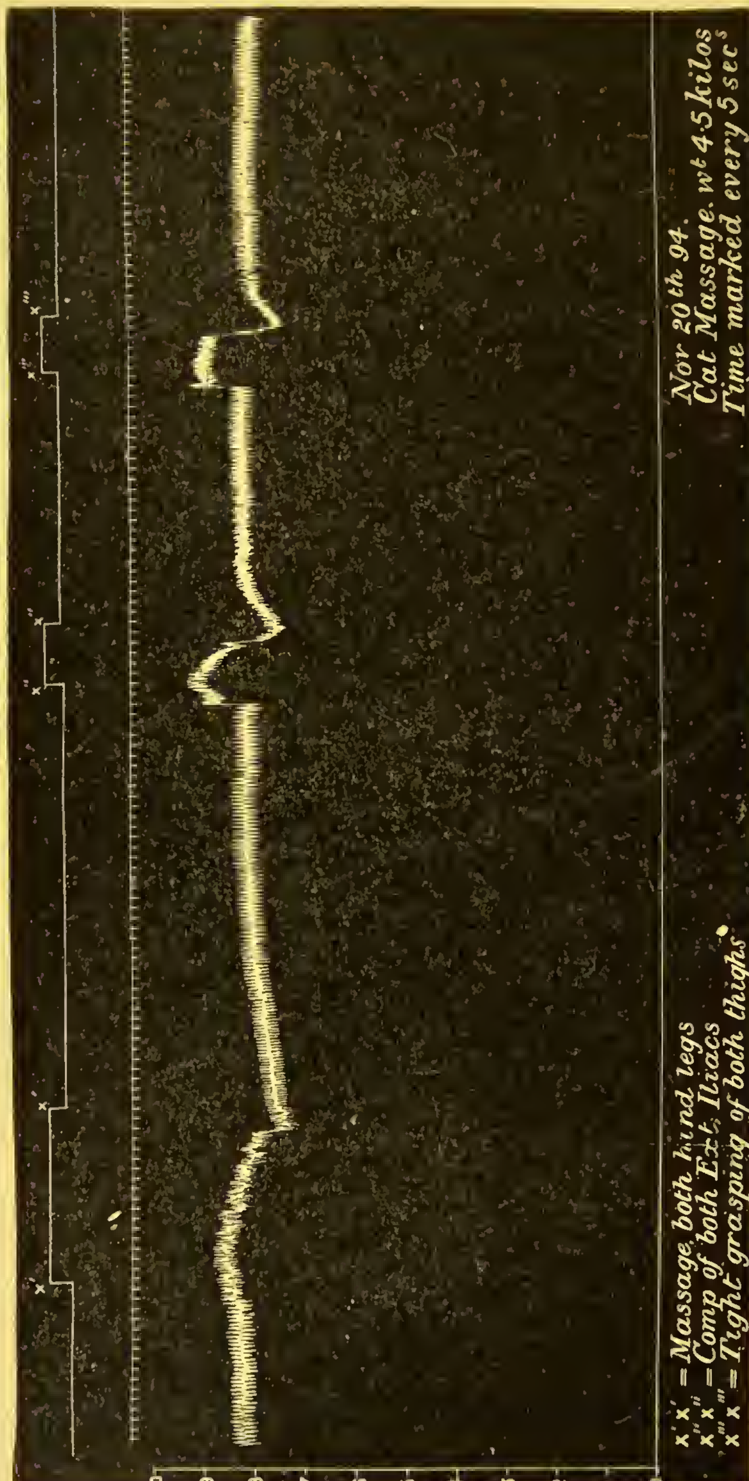


FIG. 165.—Tracing showing the effect of massage on blood pressure, first causing a slight rise, and then a distinct fall. Brunton and Tunnicliffe. This tracing was taken by Mosso's sphygmomanometer. (Fig. 93, p. 70.)

resistance which the flow of blood through the arterioles and capillaries has to overcome is lessened, and the work of the heart lightened. The weariness, the weight, and the discomfort of the limbs are removed, and the restlessness and irritability of the patient lessened. (Figs. 163 and 166.)

The combined effect of rest and massage is that the heart beats more slowly, beats more easily, has a longer period of repose between each beat, and less work to do at each systole, and thus the process of repair is allowed to begin.

The lessened resistance allows each cavity to contract more perfectly, the longer pause allows each cavity to become more

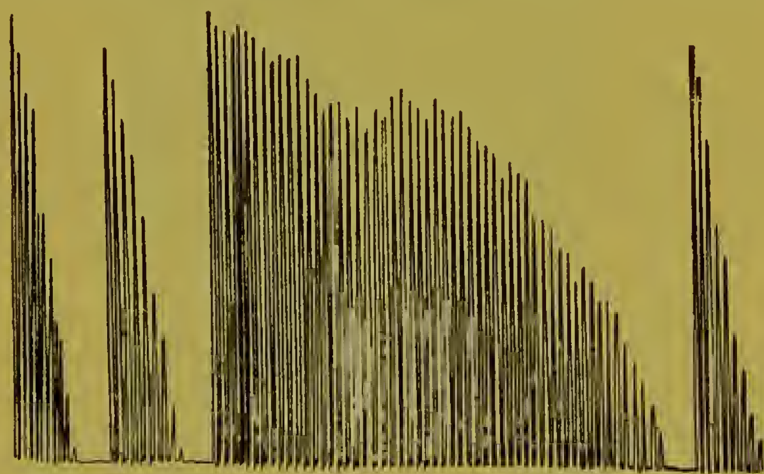


FIG. 166.—To show the relief from fatigue produced by massage. (After Maggiora and Vinaj. *Blät f. Klin.* : *Hydrotherapie*, 1892, p. 6.) 1. The fatigue curve of the left hand raising a weight of 3 kilogrammes every two seconds. 2. The fatigue curve of the left hand. 3. The fatigue curve of the left hand after five minutes' massage. 4. That of the right hand without massage. This tracing is taken by Mosso's ergograph. (Fig. 164.)

full of blood, the larger pulse-wave sent into the vessels at each ventricular contraction increases the amplitude of the pulse in the arteries, and thus brings about a more efficient self-massage in the arterial walls, and consequently a more efficient return of blood and lymph from the veins and lymphatics, which accompany the arteries in their sheaths.[1]

The heart itself, by means of its more efficient self-massage, gets rid of its waste products, is better supplied with blood, and gradually becomes stronger and stronger, until finally many patients who seemed moribund recover under the influence of

[1] *Vide* Fig. 1, p. 6.

rest and massage to such an extent that they may become practically well and remain so for years.

But it is not only on the heart and vessels that the influence of rest and massage and the consequent improvement of the circulation is noticed. On account of the increased circulation through the muscles, waste products are more thoroughly oxidised, and, the massage taking the place of exercise, a better appetite for food is produced, whilst the diminished congestion of the liver, stomach, and intestines improves digestion, and thus lessens flatulence. Massage to the abdomen aids this process: it tends to cause expulsion of gas from the stomach and intestines, and thus decreases the

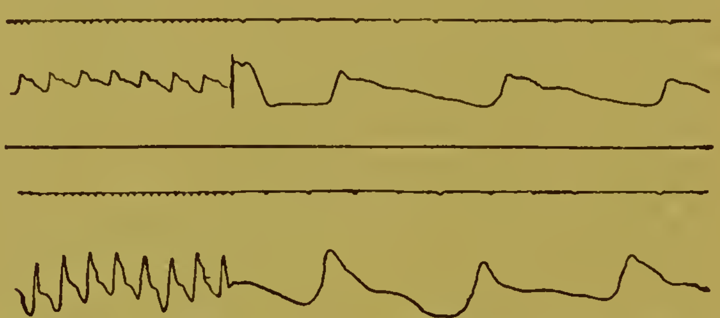


FIG. 167.—Pulse tracing, showing the effect of massage and graduated movements. Each tracing is taken partly with a slow and partly with a quick movement of the sphygmograph. The upper shows high tension and a feeble heart; the lower shows less tension and a stronger heart. These tracings I owe to the kindness of Dr Gustav Hamel, to whose treatment I had recommended the patient.

mechanical interference which the abdominal distension exerts upon the lungs and heart. The freer circulation tells upon the kidneys also. The urine becomes more abundant in quantity, albumen disappears, waste is more freely eliminated, and absorption goes on both from the inter-cellular tissue and serous cavities, so that the œdema of the limbs and accumulation of fluid in the peritoneal or pleural cavities become absorbed, and the œdema, ascites, or pleural effusion disappears. Pleural effusion is, of course, a very serious complication in valvular disease, encroaching as it does upon the available breathing space, and its appearance should always be carefully watched for, more especially as its occurrence is often insidious. It is, however, less common and less disturbing than abdominal distension by gas or water, or both.

Effect of Flatulence on the Heart.—Flatulent distension without ascites is very common indeed, and so is flatulent distension with ascites; but ascites without flatulence is rare. The relief which patients with cardiac disturbance feel when flatulence escapes from the stomach is very marked, not only in cases of valvular disease, but in cardiac weakness and in angina pectoris. The *modus operandi* of gastric distension in disturbing the action of the heart is probably twofold. It may depress it reflexly (Fig. 168) or mechanically (Fig. 169.)

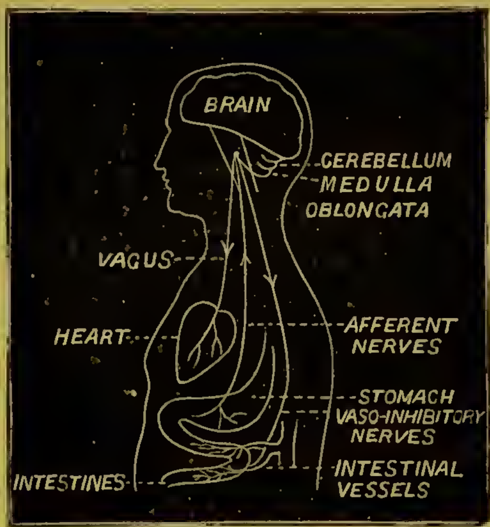


FIG. 168.—Diagram to show the nervous mechanism by which the action of the heart may be depressed by irritation of the stomach. The reflex irritation of the vagus may render the heart's action simply weak, or slow and weak.

The heart rests upon the upper surface of the stomach, with only the thin diaphragm between, and if the stomach is distended it tends to tilt the heart up by altering its position; it brings the apex close to the chest wall, and may thus cause palpitation. Not only so, but it seems also, by altering the axis, to interfere with the heart's action, and may produce distress or even death. Several years ago I saw a notice of a man who died suddenly, and on post-mortem examination he was found to be perfectly healthy, but the stomach was distended with a mixture of potatoes and milk. This had begun to ferment, and the pulpy mass being of an adhesive character, the gas was unable to escape from it, and caused such distension of the stomach that death occurred.

The mechanism here is, of course, uncertain, because the acute distension may have produced reflex stoppage of the heart, but in all probability the mechanical effect had a great deal to do with it. A year or two ago I saw another similar case recorded, where death was put down to tea. In this instance the bread and tea had apparently formed a mass like the potatoes and milk in the former case, and had a similar effect. In former times one mode of punishing by death

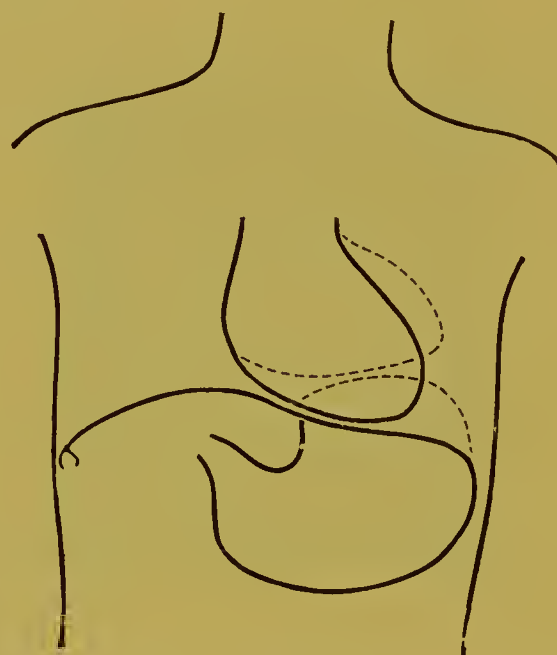


FIG. 169.—Diagram to show the effect of flatulence on the heart. The heavy lines show the normal position of the viscera. The dotted lines show their position when the stomach is over-distended.

was to make the condemned person drink bull's blood warm from the vessels of the slaughtered animal.[1] Blood in itself is not a poison, but as the criminal had to drink it in large quantities it coagulated in the stomach and formed a solid clot which, either reflexly or mechanically, caused death.[2] Under ordinary circumstances distension of the stomach, unless extreme, will not displace the heart and encroach upon the lungs, because the abdominal walls will yield, and the intestines,

[1] Marx, *Giftlehre*, vol. i., p. 268. *Herodotus*, Book III., Thalia, cap. 15.

[2] This explanation was known to Pliny, *Hist. Nat.* L. xi., c. 38, sect. 90, quoted by Marx.

partially distended as they usually are with gas, will become compressed before any displacement of the heart can occur. But if the abdomen is distended by fluid, or if it is constricted by a belt or by corsets, flatulent pressure, being prevented from exerting its force in a downward or outward direction, will push the heart up, and death may result. For this reason, as was shown by the Hyderabad Chloroform Commission, tight-lacing is dangerous during the administration of anæsthetics.[1] It tends to increase the liability to palpitation, and explains the efficacy of the common practice of at once loosening the corsets in cases of fainting.

Classification of Drugs—Use of Drugs in Cardiac Disease.—But useful and important as rest and massage are in the treatment of cardiac disease, they are not the only instruments for treatment in the hands of the physician. We possess many drugs which have a powerful action on the heart and vessels, and are of the utmost service in cardiac disease. We may divide such into (1) cardiac nutrients, (2) cardiac tonics, (3) cardiac stimulants, (4) cardiac depressants, (5) vascular contractors, and (6) vascular dilators. In addition to these, we have a number of drugs which have a less direct action upon the heart and vessels themselves, but rather affect tissue change, and influence the heart indirectly through other organs. The best cardiac nutrient is, of course, well aërated blood with a proper proportion of nutrient matter and little waste product. The nutrient materials have been investigated one by one in experiments at first upon the frog's heart (Figs. 21, 22, 31, and 170), and latterly upon the mammalian heart. The method of keeping isolated organs alive by artificial circulation was invented by Ludwig, and in the first experiments which he and his scholars made upon the frog's heart they used a simple solution of common salt of about ·5 to ·6 per cent., that is to say, about 2½ grains to the ounce. When this was circulated artificially through the frog's heart it continued beating for a length of time, but gradually the pulsations became slower and feebler, and at length ceased altogether. The addition of diluted blood usually made the heart beat more strongly for a longer period, and when it stopped the stoppage was not due to exhaustion of the nutrient material, but the accumulation of waste. This was

[1] *Lancet*, 1890, vol. i., p. 662.

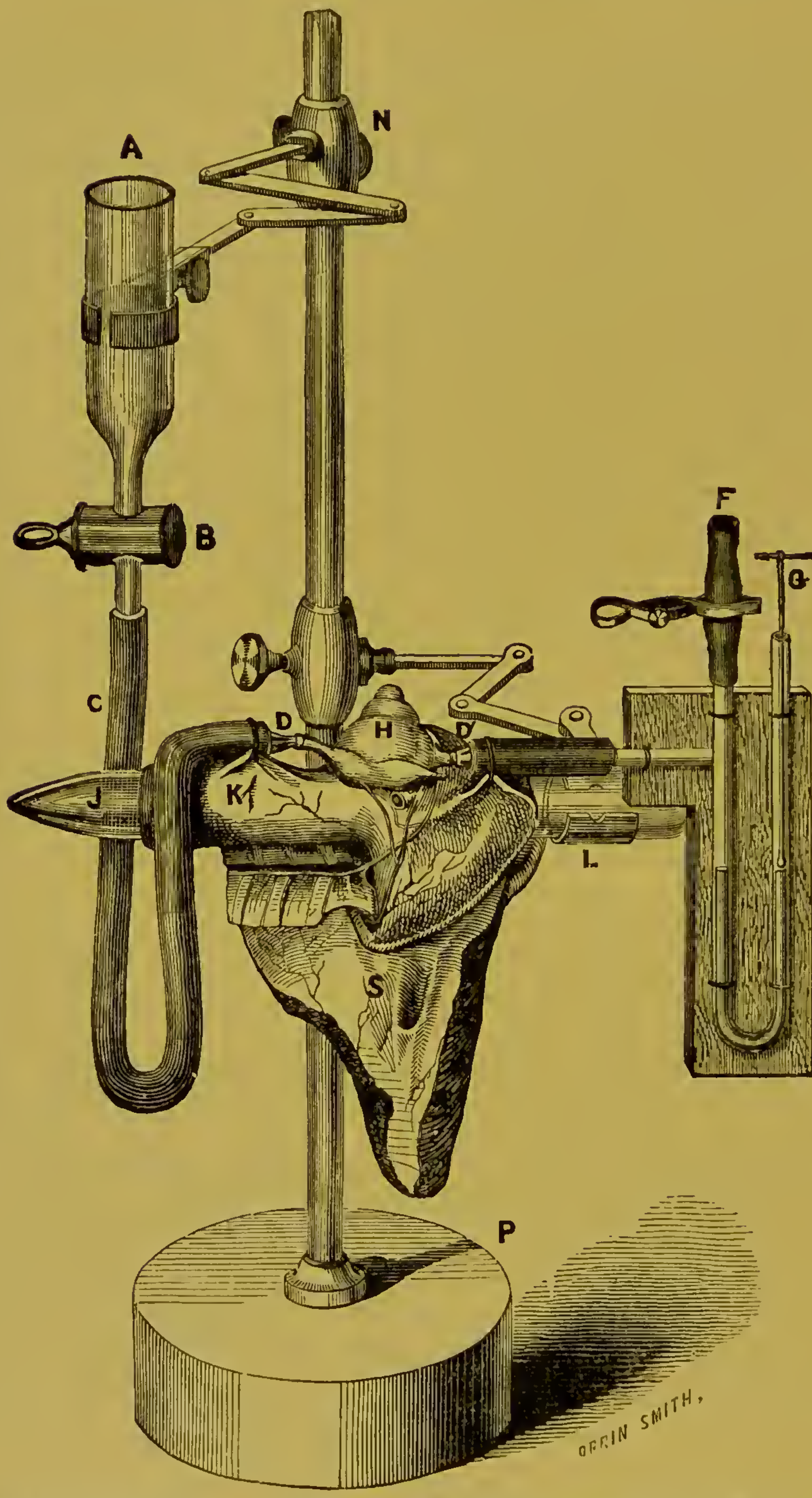


FIG. 170.—Ludwig and Coats' frog-heart apparatus. A, is a reservoir for serum. B, a stopcock to regulate the supply to the heart. C, a piece of caoutchouc tubing connecting A and D. D, a glass cannula in the vena cava inferior. D′, another in the aorta. E, a manometer. F, a piece of tubing closed by a clip, to allow of the escape of serum. G, a fine pen, floating on the mercury in E. H, the frog's heart. J, a scaled glass tube, passed through the œsophagus K, and firmly held by a holder L. M, a nut which allows L to be moved up and down. N, a second holder to support A. P, a stand with upright rod. S, a flap of skin to cover the heart and prevent drying. V, the vagus.

shown by the fact that a frog's heart when apparently dead may be revived, and again commence to beat when the waste products are washed out by perfusion with normal saline solution containing a minute quantity of sodium hydrate.[1]

Cardiac Nutrients.—An interesting and important discovery was made by Ringer, who found that when the saline solution was made with tap-water it maintained the action of the heart for a very much longer time than when made with distilled water. On investigating the cause of this, he found it was the lime in the tap-water which had a stimulating effect upon the heart, and he was able to produce the same effect by adding lime in small quantities to saline solution made with distilled water.[2]

We know that a fire when allowed to burn without attention will often go out before the whole of the coal is consumed, because it is smothered in its own ash, and that if we heap ashes on the fire we tend to put it out. But the result is different if we use cinders instead of ash; and although cinders represent half-burned coal, they are sometimes very useful in keeping up a fire or in helping it to burn when it is low. In the same way the ashes, as we may term them, of the tissues tend to smother the vital fires, and to prevent the tissues from performing their proper functions; but the vital cinders, that is, substances which are derived from albumens and are on the way to urea or uric acid, may be very useful. Amongst these we have a series of bodies to which the term of purin bodies has been applied—xanthine, hypoxanthine, methylxanthine, dimethylxanthine or theobromine, and trimethylxanthine or caffeine. All these bodies are probably injurious in large quantities, but just as a few cinders may help a fire, so when used in small quantities they are often very useful. Beef-tea and extracts of meat have little or no nutritive action, and life cannot be sustained upon them, but they are useful stimulants, as was shown by Parkes in the Ashanti campaign;[3] and in disease they act as cardiac stimulants, though only slightly as cardiac nutrients. Amongst the most powerful cardiac nutrients appears to be glucose; for Locke

[1] Gaule, *Arch. f. Anat. u. Physiol.*, Physiol. Abt., 1878, s. 294.

[2] Ringer, *Jour. of Physiol.*, iv., p. 29.

[3] Parkes, "On the Issue of a Spirit Ration, etc." London, Churchill, 1875.

found in his experiments that the addition of glucose, even in very small quantity, to a saline fluid greatly increased its

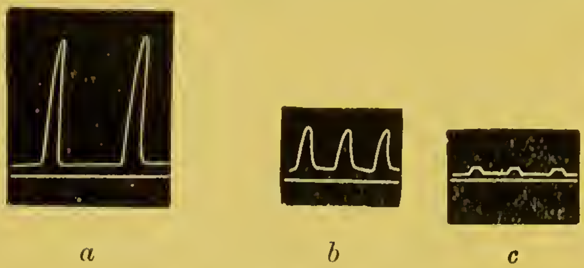


FIG. 171.—After Ringer. Tracings showing the effect of simple NaCl solution in weakening the pulsations of the apex of the frog's heart. The tracing *a* was taken soon after the blood was replaced by NaCl solution; *b*, after a longer period; and *c*, after a still longer time.

FIG. 172.—After Ringer. Shows the effect produced upon the beat of the frog's heart fed with NaCl solution by the addition of a trace of calcium chloride. The beats in this case are induced by an induction shock.

nutritive effect upon the isolated mammalian heart. Other sugars have less action. Their nutritive effect apparently runs

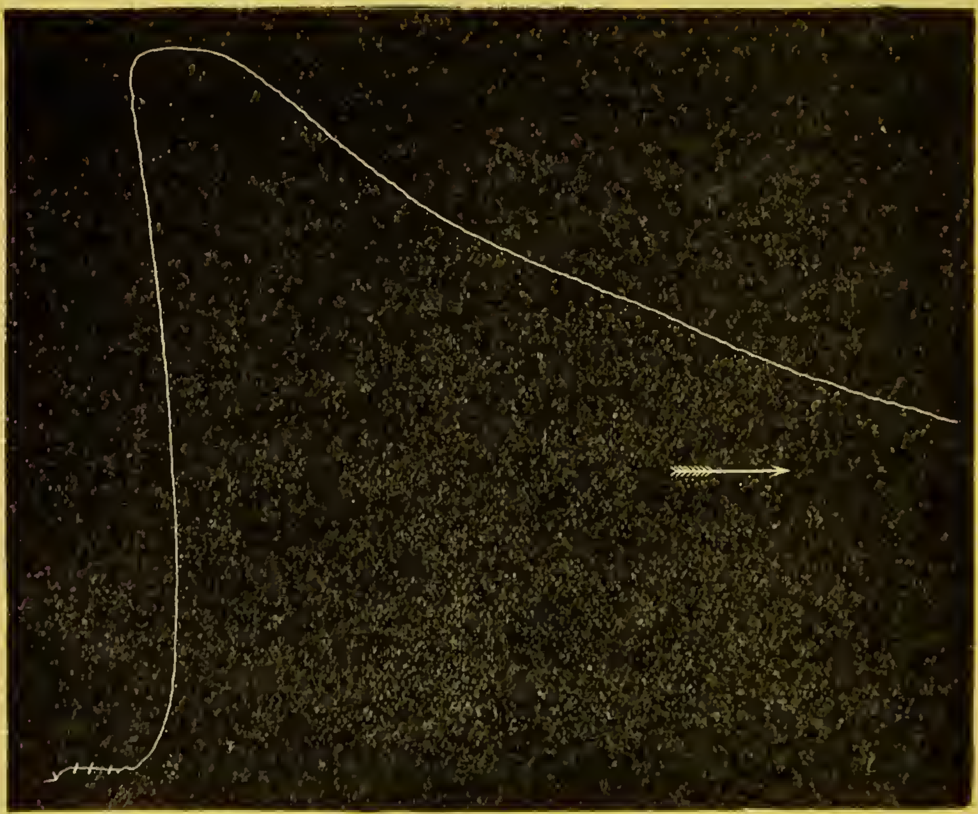


FIG. 173.—Tracing showing enormous contraction of the gastrocnemius of the frog produced by a solution of caffeine. (Lauder Brunton and Cash, *Journ. of Physiol.*, ix., p. 119.)

parallel with their susceptibility to fermentation, glucose standing far ahead of the others. Caffeine in large doses acts as a

muscular poison, and tends to cause strong contraction, ending in rigor of the muscle. Its effect in small doses upon the heart appears to be that it increases the muscular contraction, and strengthens the ventricular beats.

Digitalis and its Congeners.—The most important drug of all, however, in the treatment of heart disease is digitalis. Although this drug has been used for a long time, yet it is only within the last forty years or so that its action has really become generally understood. Even when I was a student, digitalis was looked upon as a cardiac depressant to be used with great care in enfeebled hearts, whereas now it is universally regarded as a cardiac tonic. Although Blake in 1839 showed that digitalis injected into the arterial system greatly raised the blood pressure, yet the physiological action of the drug was not further investigated until Traube made his experiments in 1862 on the mammalian circulation, and Fagge and Stevenson on the frog's heart. In 1865 I wrote my Thesis on Digitalis, and, I think, for the first time brought into relation the double action of digitalis both on the heart and the vessels, as well as giving the first definite proof that the cardiac action in mammals was actually strengthened and not weakened by this drug.[1]

Digitalis is an example of a very widely distributed group of poisons, many of which are used in various parts of the world for poisoning arrows, either for use in the chase or in war. Those which are most commonly used in medicine are the strophanthus hispidus and squill (*Scilla maritima*). Amongst those occasionally but less frequently employed are, casca or sassy bark (*Erythrophlœum guineense*), lily of the valley (*Convallaria majalis*), Canadian hemp (*Apocynum cannabinum*), pheasant's eye (*Adonis vernalis*), and Christmas rose (*Helleborus niger*). Other plants having a similar action, but not used, are *Antiaris toxicaria* (upas), *Nerium oleander*, *Acocanthera* (oubain), *Thevetia grandiflora*, and *Coronilla*. A poison having a similar

[1] Brunton, "On Digitalis," pp. 28, 31. Churchill, London, 1868. Reprinted in *Collected Papers on Circulation and Respiration*, pp. 52, 55. Macmillan, London, 1906. This paper was presented as a graduation thesis to the University of Edinburgh in 1866, but was not published until 1868. This paper also gives the early literature of the subject.

action is obtained from the skin of toads. It is called phrynin, and though not employed much in medicine, it has proved useful. The story is told that the husband of an Italian woman was dying of heart disease, with dropsical limbs and all the usual accompaniments. As his death was so slow, his good wife thought she would quicken his journey into the other world, and accordingly she went into the garden, where she found several toads. These she dropped into the wine her husband was to drink; but instead of his dying forthwith, as she expected, he began immediately to get well, the phrynin from the toad's skin having had upon him the same beneficial effect that a course of digitalis would have had.

Résumé of the Action of Digitalis.—Digitalis acts on the cardiac muscle, the intrinsic cardiac nerves, and the vagus

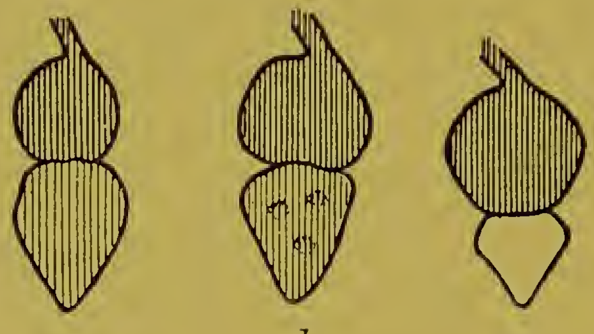


FIG. 174.—Diagram to show the action of digitalis on the frog's heart; *a* is the normal heart in which both auricle and ventricle are filled with blood during the diastole; *b* is the heart with the ventricle becoming contracted and showing the yielding pouches; *c* is the heart fully under the influence of digitalis, with the ventricle firmly contracted so that it will not admit any of the blood which distends the auricle.

centre in the medulla. It also affects the arterioles, causing them to contract, and probably it has upon them also a two-fold action, as on the heart, and stimulates both the contractile muscular walls and the nerves which go to them. The action upon the heart of the frog is very marked and characteristic, and the action here is less complicated than in mammals, inasmuch as the heart itself is less under the control of the central nervous system, and is less readily affected by alterations which may occur in the vessels. When the excised heart of a frog is either laid in a solution containing the active principles of digitalis, or is connected with an apparatus by

which serum containing these principles may be circulated through it, changes are observed, which may be divided into changes in rate of pulsation and changes in character of pulsation. The heart first of all begins to pulsate more slowly, and at the same time more powerfully; the contractions become gradually stronger, and the relaxation or diastole becomes less perfect, so that finally the heart stands still altogether in a state of complete contraction. If the heart which is thus standing still be forcibly dilated, by passing fluid into its interior under pressure, pulsation will recommence. Occasionally during the process of contraction small points on the surface of the heart may be observed, which remain dilated, and look like small purple pulsatile pouches on the surface of the organ.[1] The nature of these pouches has not been definitely ascertained, but it is not improbable that they are due to slight injury of the muscular fibre in the process of removing the heart from the body of the frog. When the heart of a frog is left *in situ*, and is merely exposed to view by opening the thorax of the animal, and dropping a solution of digitalis upon it, the same phenomena are observed. They are unaltered by the use of atropine, and are supposed to be due to the action of the drug upon the muscular fibres of the heart itself.

Action of Cardiac Tonics on the Embryonic Heart; Relation of their Action to Oxidation.—J. W. Pickering has found (*Journ. of Physiol.*, 1893, vol. xiv.) that digitalin has the same action on the embryonic as on the adult heart, rendering the systole very powerful and the diastole imperfect, so that at last the heart stops in tonic contraction, and becomes very pale (*cf.* Fig. 174). Caffeine slightly increases both the frequency and energy of the systoles, and finally causes stoppage in systole. He points out (p. 436) that the action of these two drugs on the heart may be due to their effect upon oxidation, for they are *par excellence* the drugs which produce tonic contraction, and as Lauder Brunton and Cash have shown (*St Bartholomew's Hospital Reports*, 1882), they accelerate the oxidation of protoplasm. Other drugs which retard oxidation tend to produce an atonic condition of the embryonic heart.

[1] Fagge and Stevenson, *Roy. Soc. Proc.*, xiv., p. 270.

LECTURE VI

Action of Digitalis in Mammals—Uses of Digitalis—Action of Digitalis on Œdema—Toxic Action of Digitalis—Action of Digitalis on Arterioles—Stages in the Action of Digitalis—Difference between Digitalis and other Cardiac Tonics—Action of Adrenaline on the Heart and Vessels—Action of Strychnine on the Heart—Action of Caffeine and other Purin Bodies—Drawbacks to the Action of Digitalis and other Cardiac Tonics—Removal of these Drawbacks by Combination—Vaso-dilators: Amyl nitrite, isobutyl nitrite, hydroxylamine, nitroglycerine, nitro-erythrite, nitromanite, sodium, and other nitrites.

Action of Digitalis in Mammals.—In mammals, digitalis causes increased contraction of the muscular fibres, both (1) in the heart and (2) the arteries. This increased contraction appears to be partly due to the action of digitalis on the muscular fibres themselves, but its effect upon the muscle is greatly modified by its action upon the nervous system. Its action is exerted especially upon the medulla oblongata, and it appears to affect first the inhibitory centre of the vagus and the vaso-motor centre for the vessels. When small doses are given, the effect appears to be limited to these centres, but when the administration is carried to the extent of poisoning, the adjacent respiratory and vomiting centres are also affected. From stimulation of the vagus centre, the pulse becomes slow, and the diastole more complete, while at the same time the stimulation of the muscular fibre of the heart makes its contractions more powerful. Its beats thus become much more efficient; the longer intervals between them afford the heart time for recuperation; the more complete diastole allows a larger quantity of blood to accumulate in its cavities, the more powerful systole drives this onward, the self-massage of the

heart becomes more complete, and all the good effects which I have mentioned as occurring from this are noticed after the action of digitalis. One consequence which is of special interest is its diuretic action. This is partly due to the rise in blood pressure which it produces, and which raises the pressure in the glomeruli, drives the blood more quickly through the kidneys, and causes a more rapid secretion of urine. At the same time it is probable that digitalis has a certain stimulating effect on the secreting structures in the kidneys themselves, a stimulation which may extend also to other parts of the genito-urinary tract. This effect, however, is not so great as that produced by caffeine, and the diuretic action of digitalis is probably exerted chiefly through the circulation. When digitalis acts upon a healthy man so as to produce diuresis, the drain of fluid becomes so great that, as I have found in my own experiments, the thirst it induces becomes intolerable, and water must be taken in order to allay it.[1]

In cardiac diseases with œdema, or accumulation of fluid in the serous cavities, such drinking is unnecessary, as the fluid drained away from the blood by the kidneys is supplied by absorption from the subcutaneous tissue or from the serous cavities.

Uses of Digitalis.—Not only does the circulation in the tissues generally improve under digitalis, but the nutrition of the heart is increased by more efficient circulation through the coronary vessels; dilatation is lessened; the muscular rings around the auriculo-ventricular orifices contract more strongly, the mitral and tricuspid valves close them more efficiently, and regurgitation is lessened. In cases where the valvular incompetency is solely due to dilatation and not to changes in the valves themselves, the incompetency may be completely cured.

The arteries likewise benefit, as the slower and stronger beats of the heart increase the self-massage of the artery in its sheath, and the same increased pulsation aids the circulation in the veins, as already described. The venous circulation is farther

[1] Lauder Brunton on "Digitalis," *Collected Papers*, p. 83. Macmillan & Co., London, 1906.

aided by increased suction-power of the heart (Fig. 125, p. 94), which contracts more rapidly and completely. Diminished

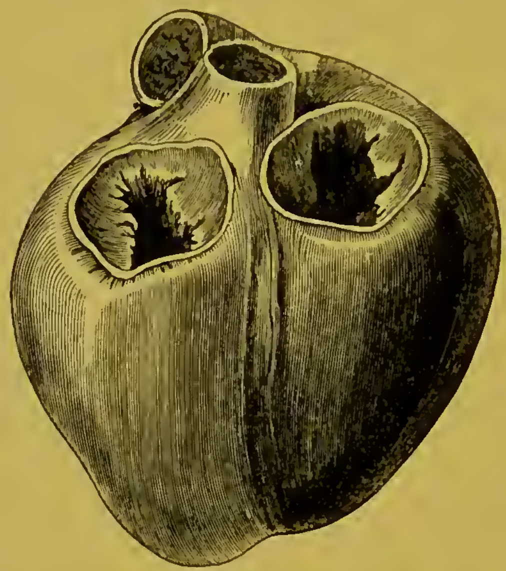


FIG. 175.—Heart fully distended, showing insufficiency of the valves to close the mitral and tricuspid orifices.

regurgitation combines with increased circulation in the veins to lessen venous congestion, and thus tends to increase the

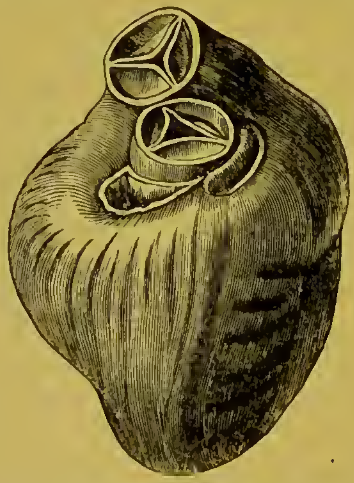


FIG. 176.—Heart in full systole, showing the mitral and tricuspid orifices so diminished by the muscular contraction that the valves close them easily.

FIG. 177.—The same heart as in Fig. 176, from another point of view.

secretion of urine. For venous congestion in the kidneys tends to compress the arterioles and tubules in the organ, and thus

lessen secretion; and digitalis, therefore, in cases of venous congestion probably acts as a diuretic in four ways—(1) it increases the blood pressure in the glomeruli; (2) it lessens the resistance which the pressure of the distended venous radicles in the kidney opposes to secretion; (3) it probably acts as a stimulant to the secreting cells of the kidney; and (4) it increases the volume of blood, and somewhat alters its composition by causing absorption from œdematous tissues and serous cavities. When it causes absorption of ascitic fluid from the abdominal cavity it may act as a diuretic in a fifth way, viz., by lessening the resistance opposed to the secretion of urine by the

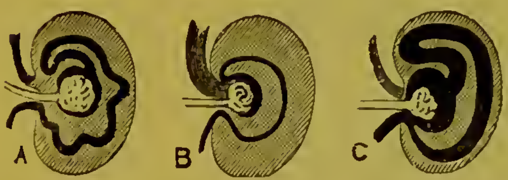


FIG. 178.—Diagram to show the effect of venous congestion and of obstruction of the ureter or tubules on the kidney. A, normal kidney, with artery in the centre of the hilus. The artery ends in a glomerulus from which a urinary tubule passes into the ureter, which is shown passing out of the hilus below the artery. The renal vein is shown above the artery in the hilus. B shows congestion of the vein, with consequent compression of the artery and tubule. C shows obstruction of the ureter and tubules.

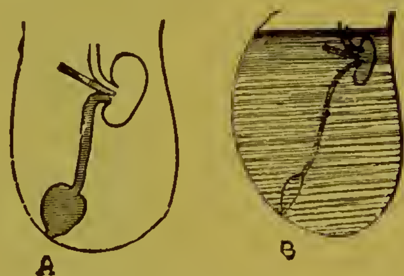


FIG. 179.—Diagrammatic section of the abdomen: A, in the normal state; B, in advanced dropsy, where the ascitic fluid compresses the kidney itself and also the ureter, so that the secretion of urine is hindered in two ways: (1) by pressure on the outside of the kidney, and (2) by pressure on the inside of the kidney from the tension in the urinary tubules.

pressure of the ascitic fluid on (*a*) the kidney itself, and (*b*) on the ureters. From this manifold action of digitalis as a diuretic it is evident that when its action is once fairly established in a water-logged patient, the amount of urine secreted for some days may be enormous.

Action of Digitalis on Œdema.—As I have already mentioned, the diuretic action of digitalis may cause so much water to be withdrawn from the blood that it produces a consuming thirst in a healthy man.[1] In a dropsical one, the fluid lost through the kidneys is made up by absorption from the tissues, and this is one way in which digitalis reduces œdema. But it is

[1] Lauder Brunton on "Digitalis," Notes of March 17 and 19, 1865. *Collected Papers on Circulation and Respiration*, p. 83.

probably not the only one. For digitalis stimulates the vaso-motor nerves, and in this way tends to prevent the exudation of fluid from the blood-vessels, which produces œdema. It is universally acknowledged that venous obstruction tends to produce œdema, but at the same time œdema may occur without any obvious venous obstruction, as in angio-neurotic œdema. Moreover, venous obstruction may exist without œdema, as was

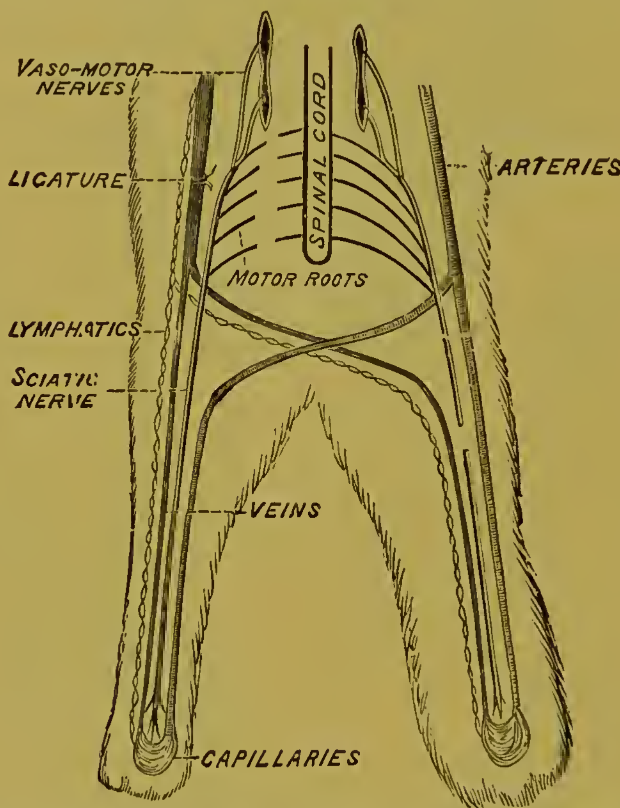


FIG. 180.—Diagram of Ranvier's experiment on dropsy. The vena cava is ligatured, and in the left leg the trunk of the sciatic has been divided so that both the motor and vaso-motor nerves contained in it are paralysed. On the right side the motor roots of the sciatic alone are divided and the vaso-motor left uninjured. There is thus motor paralysis on both sides, but vaso-motor paralysis and dropsy only on the left side.

shown by Ranvier, who tied the vena cava in a dog, and found that although venous congestion was thus produced in both legs, no œdema occurred in the leg where the vaso-motor nerves were left intact, but occurred in the other where the vaso-motor nerves were divided.

Another benefit resulting from diminished venous congestion is improved digestion and assimilation. The liver, which under increased venous pressure may have become so swollen (*cf.* Fig.

14, p. 16) as to reach even below the umbilicus, returns more or less to its normal size, and the obstacle which had existed to the return of venous blood from the stomach and intestines, nearly all of which has to pass through the liver, is removed (Fig. 181).

FIG. 181.—Diagram to show the return of venous blood from the stomach and intestines through the liver.

The circulation through these organs becomes better, digestion and absorption improve, flatulence is lessened, and the patient's nutrition improves.

Toxic Action of Digitalis.—All these are the advantages which we gain from the proper administration of digitalis; but when carried too far, a toxic action occurs, and one of the first

symptoms is nausea and vomiting. This may be due simply to extension of the irritation in the medulla from the vagus and vaso-motor centres to the vomiting centre, but it may be due also, to some extent, to a local irritation of the stomach by the digitalis being secreted into it in the same way as tartar emetic, or the toxins of cholera. In medical practice, gastric irritation is usually one of the first indications that the physiological effect of digitalis is passing into its toxic action. Some-

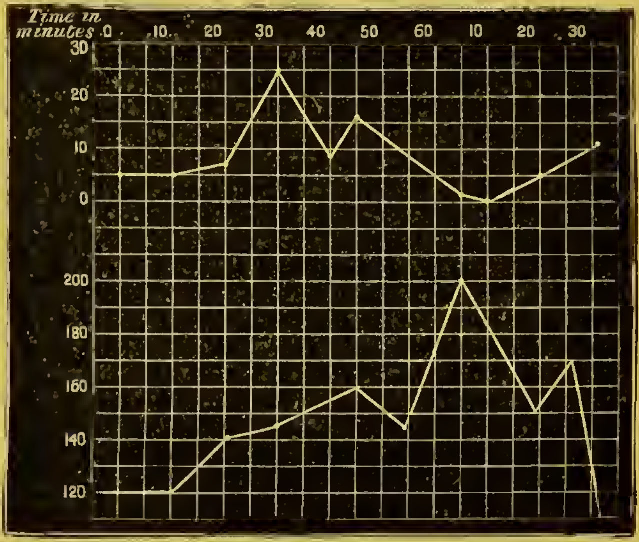


FIG. 182.—Diagram to show the relation between blood pressure and the secretion of urine after the administration of erythrophlœum. The lower tracing shows the blood pressure in millimetres of mercury. The upper shows the secretion of urine in minims per ten minutes. It may be noted that when the blood pressure rises to its maximum of 200, the secretion of urine falls to zero.

times, however, the pulse becomes abnormally slow, even before sickness occurs. If the warning given either by sickness or by the pulse is attended to, and the administration of the drug is stopped, usually no further disadvantage occurs; but if these warnings be unheeded, excessive vomiting may set in, collapse may occur, and the secretion of urine may be entirely arrested. The secretion of urine may cease at the time when the blood pressure is at its maximum, as I found along with Mr Power in the case of digitalis, and along with Mr Pye in the case of strophanthus. The stoppage of secretion is exactly like that

which occurs from ligature of the renal artery, and in all probability it is due to spasm of these arteries stopping the circulation through the kidney. As the pressure begins to fall and the arteries relax, urine is again secreted, but it is often albuminous, exactly like the urine secreted after the arteries have been ligatured and then released.

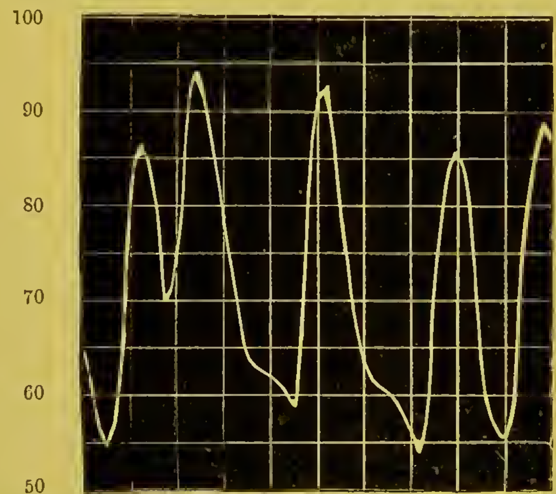


FIG. 183.—Tracings to show the first stages of the action of digitalis. Brunton and Meyer —Tracing of the oscillations of blood pressure in a dog. There are nearly 5 beats of the heart in the tracing, and the pressure falls to 55 mm. of mercury and rises to 94.

Action of Digitalis on Arterioles.—The rise of blood pressure which digitalis produces was attributed by Traube and von

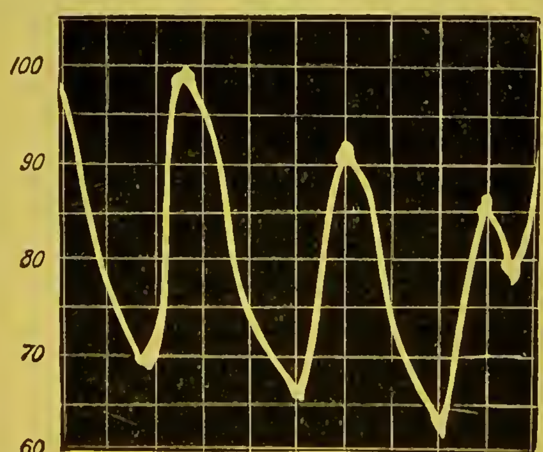


FIG. 184.—Tracing from same animal after the administration of digitalis. The slowing of the heart is very marked, the pressure is somewhat raised.

Bezold to increased action of the heart, and they left the arterioles altogether out of account as a factor in its production.

In my thesis, presented to the Edinburgh University in 1866, I pointed out the importance of the arterioles, and in the winter

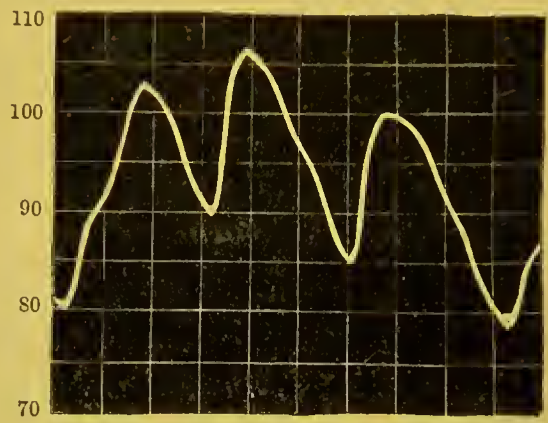


FIG. 185.—Tracing from the same animal when the action of digitalis is more pronounced. The difference between this and the previous tracing does not consist so much in any further slowing of the pulse but in the smaller oscillation and the rise in tension.

of 1867-68 I obtained, in conjunction with A. B. Meyer, experimental evidence of this action.[1] We noticed that after

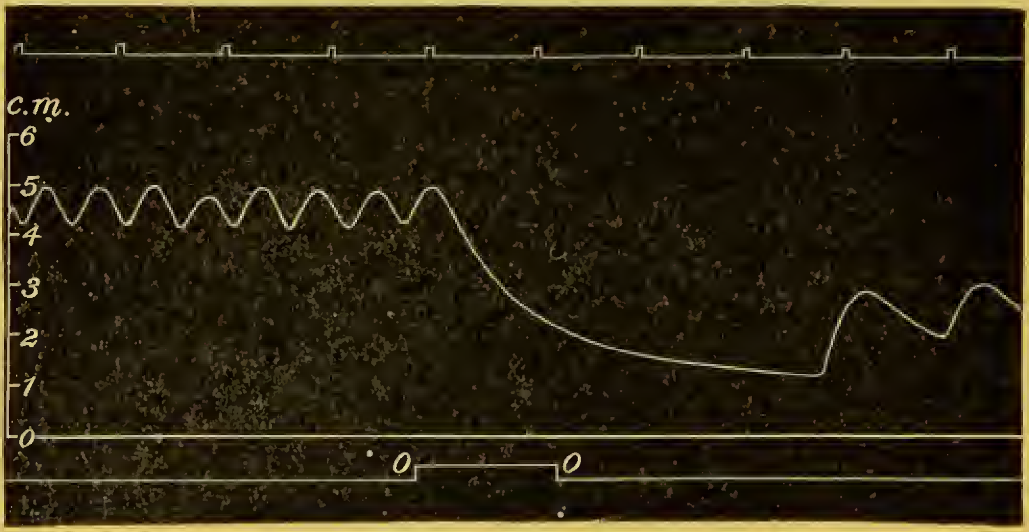


FIG. 186.—Tracing of the blood pressure of a dog during arrest of the heart by electrical stimulation of the vagus before injection of digitalis. It will be noticed that during the stoppage the blood pressure falls to within 1·5 cm. of the abscissa.

the injection of digitalis into the veins of a dog, the pressure in the arteries not only rose higher than before, but it fell more slowly during diastole. Had the arterioles not been contracted,

[1] Brunton and Meyer, *Journ. of Anat. and Physiol.*, vol. vii., 1873, and reprinted in *Collected Papers*, p. 141.

the higher pressure would have driven the blood more quickly through them in diastole, and so the fall would have been quicker than before, instead of being slower, as we found it to be. In order to obtain more certain proof of this, however, I then took up the question along with Dr Tunnicliffe, and instead of using the normal systole of the heart we prolonged it greatly by irritation of the vagus. The results we arrived at entirely confirmed my previous observations; for, although the pressure was considerably raised in the arteries by the administration of digitalis, it fell very much more slowly than in the normal

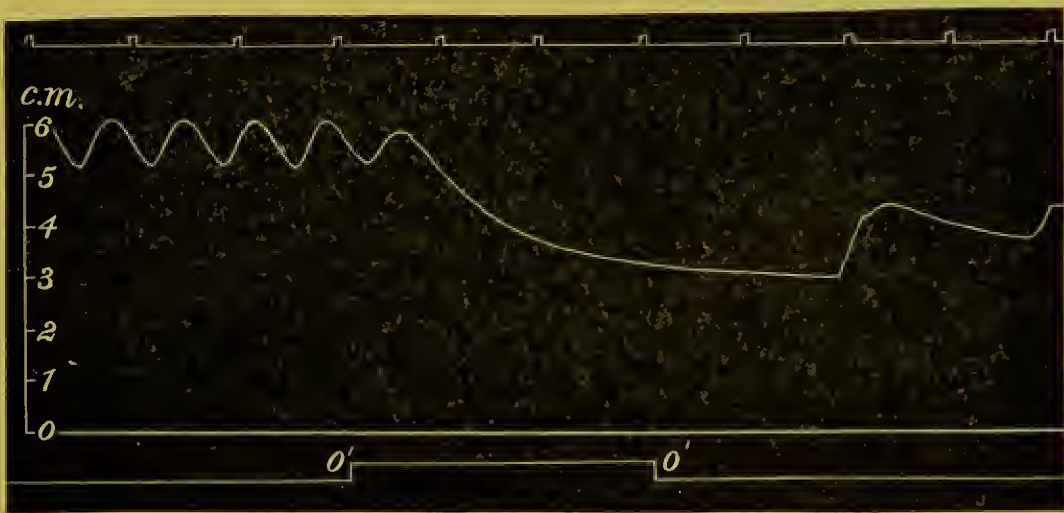


FIG. 187.—The same experiment as in Fig. 186, but after the injection of digitalis. Although the arrest of the heart is longer than in the previous experiment, the blood pressure only falls to within 3 cm. of the abscissa instead of to 1·5 cm.

animal, while the heart was standing still from irritation of the vagus. I need not enter further into the discussion of this point, as Tunnicliffe and I have gone fully into it in our paper.[1]

Stages in the Action of Digitalis.—The action of the drug may be divided into several stages. These stages have been variously described, so that the stages of different authors do not correspond. The essential part of the division is that in the first stage there is increased power, both of those parts of the nervous system connected with the heart and vessels and of the muscular fibres in them, while in the later stages more or less complete paralysis of these structures occurs.

[1] Lauder Brunton and Tunnicliffe, *Journ. of Physiol.*, 1896, vol. xx., p. 354.

We might, then, take as the—

1st stage, that in which there is *increased action* in all the nerves and muscles of the circulation; as the

2nd, that in which the *nervous system* of the heart begins *to fail*, while muscular power and the whole vascular apparatus are still intact; as the

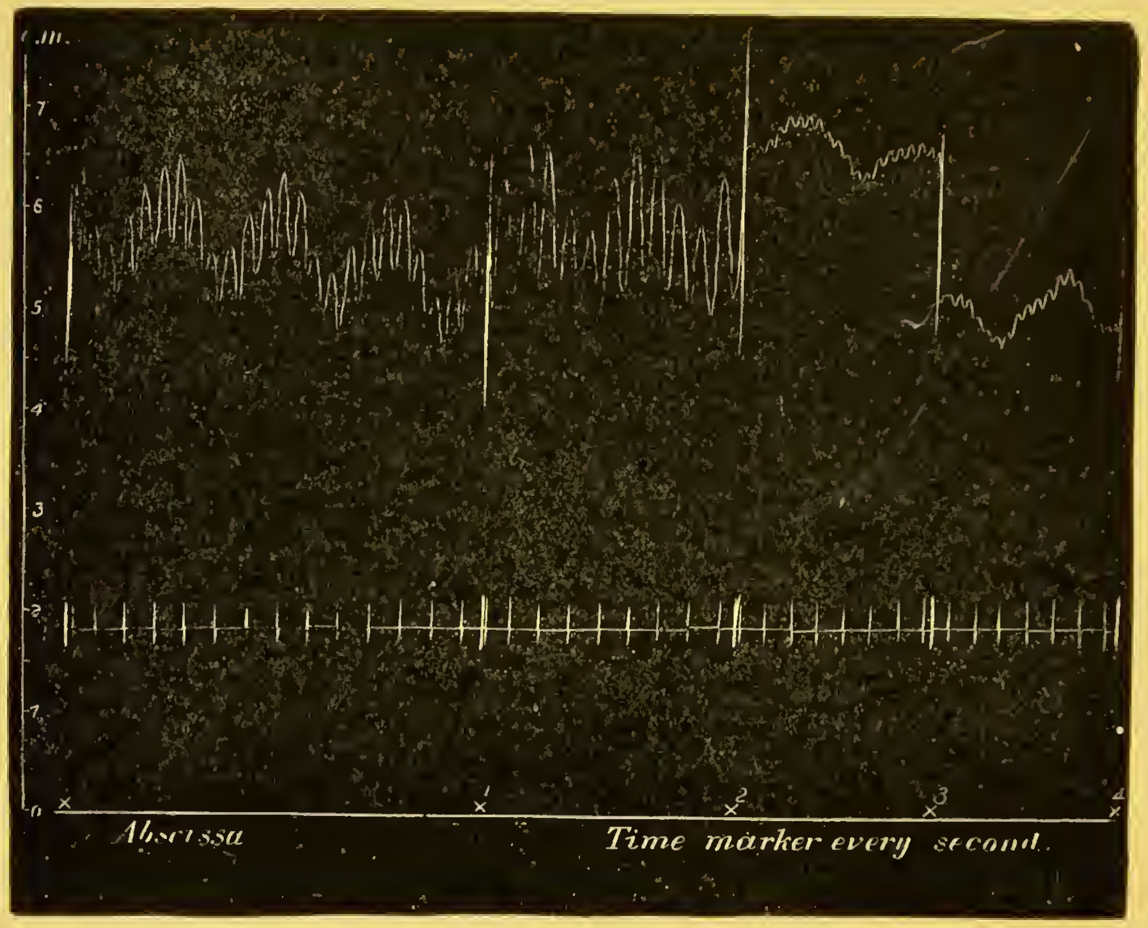


FIG. 188.—Tracings of blood pressure showing the action of digitalis. The first is normal; the second, slow pulse with rise of pressure; third, paralysed vagus with contracted arterioles; fourth, vessels relax.

3rd, that in which the *muscular fibre* of the heart begins *to fail*; and as the

4th, that in which the *vessels* become *enfeebled.*

In the first stage we have a rise of blood pressure and usually a slowing of the pulse, this slowing being due to the action of the drug both on the vagus roots and ends in the heart. Although the pulse is slow, the systole of the heart is

not prolonged, and there is, therefore, a much longer diastole during which the heart is able to rest. The blood pressure in the kidneys is increased as well as in the other organs, and the urinary secretion is therefore augmented. In the second stage, while the blood pressure continues high, the vagus becomes partially paralysed, and therefore the pulsations become at first irregular and afterwards very rapid. In this condition spasm of the renal vessels may occur, and the urinary secretions may entirely cease. When this occurs in man, the condition of the patient is dangerous. In the third stage the heart becomes feebler, and may again become regular, from failure either of the muscular fibre itself or the intrinsic ganglia. The arterioles now relax, the blood pressure begins to fall, and the urine may again become copious. In the fourth stage, the vessels dilate generally, blood pressure falls very greatly, and the heart stops sometimes in systole, as in the frog, but very frequently in diastole.

Difference between Digitalis and other Cardiac Tonics.—The differences which have been observed between the action of digitalis and its congeners are that, while digitalis affects both heart and vessels, the action of strophanthus appears to be exerted more especially upon the heart, increasing its power; while that of erythrophlœum appears to be exerted more upon the vessels.

Action of Adrenaline on the Heart and Vessels.—This substance when injected into the circulation causes a contraction of the vessels and rise of blood pressure, such as almost no other substance, except nicotine, p. 164, will produce. It is also a powerful stimulant of the heart. Unfortunately, its action is transient, and when given by the mouth, its action is much less than when given hypodermically.

Action of Strychnine on the Heart.—Another drug belonging to quite a different class, and yet most useful in cardiac disease, is strychnine. Its action is exerted slightly, if at all, upon the muscular fibre, but it greatly increases the reflex excitability of nerve centres. This is more especially marked in those of the cord and medulla, but it also stimulates peripheral ganglia, and Cash and I found that when applied to the heart it prevented the slowing or stoppage of the ventricle, which usually

occurs from the application of a ligature between the venous sinus and the ventricle.[1] In some books on Pharmacology the action of strychnine as a cardiac stimulant is to a great extent ignored; but I think that in medical practice the use of this drug as a cardiac stimulant has of late years become more and more general, and it is justified by the good effects observed from it, and explained, partly at least, by the action on the heart which Cash and I found it to have. Under its use we frequently notice that a pulse which was previously feeble, irregular, or intermittent, becomes steady, strong, and regular. No doubt, the conditions which regulate the pulse are very complicated in health, and still more in disease, so that it is difficult or impossible to be absolutely certain of the exact mode of action of strychnine; but at the same time its good effects are, I think, undeniable, and the explanation that I have given is at any rate feasible.

Action of Caffeine and other Purin Bodies.—While strychnine exerts its beneficial effect almost entirely through the nerves, caffeine and allied bodies probably exert it, more especially, through their action upon the muscular fibre of the heart and arteries and upon the secreting cells in the kidneys. This is not entirely the case, however, for all the plants which contain either caffeine or theobromine are used dietetically as nervous stimulants; tea, coffee, and chocolate being the most commonly employed, but kola and guarana being also largely used in Africa and South America. Like digitalis, caffeine stimulates the vaso-motor centre in the medulla and raises the blood-pressure by causing contraction of the vessels; but this rise, instead of being accompanied by a slow pulse, as in the case of digitalis, usually goes along with an acceleration of the heart beats. The reason of this probably is that the cardiac muscle is rendered by caffeine more irritable, so that its rhythmical stimuli follow one another more quickly, while at the same time its contraction becomes more powerful. The effect upon the kidneys is to produce a considerably increased flow of urine, and

[1] Brunton and Cash, "On the explanation of Stannius's experiment, and on the Action of Strychnia on the Heart," *St Bartholomew's Hospital Reports*, vol. xvi., 1880, reprinted in *Collected Papers*, p. 556, *cf.* p. 557.

the increase of water is accompanied also by an increase in the solids, the total effect being chiefly due to stimulation of the secreting cells. Theobromine differs from caffeine in having much less effect upon the vaso-motor centre and more effect upon the kidney itself. It therefore acts more powerfully as a diuretic than caffeine. It is sparingly soluble in water, but is rendered more soluble by trisodium phosphate, and several synthetic compounds have been introduced into medicine. One is called diuretin, which is said to be a salicylate of sodium and theobromine; agurin, which is an acetate of sodium and theobromine; an iodide of sodium and theobromine; and uropherin, which is a salicylate of lithium and theobromine. Another substance, also found in tea and coffee, theophyllin, has been made synthetically, and is sold under the name theocine. All these substances are useful diuretics, and may be given either alone or in combination with digitalis, strophanthus, or other drugs having a similar action.

Drawbacks to the Action of Digitalis and other Cardiac Tonics.—All the drugs of which we have hitherto been speaking have a tendency to cause contraction of the vessels. This tendency may interfere with their beneficial effects by causing contraction of the renal arteries, and thus checking the secretion of urine; but a greater drawback sometimes is that, by contracting the vessels generally, they raise the blood pressure and thus increase the resistance which the heart has to overcome, and consequently the work it has to do. If the heart is very feeble it may even become unable to overcome the increased tension, and sudden and fatal syncope may ensue. Fatal syncope has not unfrequently resulted from the excessive use of digitalis, and it appears to be more apt to come on when the person rises to micturate. The sudden change from a recumbent to an upright position lessens the pressure of blood in the cerebral arteries, while, at the same time, by emptying the bladder the intra-abdominal pressure is lessened, and the blood is retained in the splanchnic area. But the cases in which the heart is most likely to be stopped by digitalis are those in which the arterial pressure is already high, as in advanced Bright's disease, and where the heart has already become fatty. In such cases

digitalis must be used with great caution, for there is a double risk. On the one hand, there is the danger just alluded to of stopping the heart, and on the other, there is the risk of causing apoplexy by the arterial tension rising so high as to burst a vessel in the brain.

Removal of these Drawbacks by Combination.—Yet in many such cases we sadly want the steadying and strengthening effect of digitalis or strophanthus upon the heart, and we are able to obtain the result we desire by combining these drugs with others belonging to an entirely different class, namely, that of vaso-dilators.

Vaso-dilators.—The first vaso-dilator investigated was nitrite of amyl. Its power of causing flushing of the face was noticed by Guthrie in 1859, and Dr B. W. Richardson observed that it caused dilation of the capillaries in the frog's foot; but it was Dr Arthur Gamgee who first discovered its power of lowering the blood pressure. It was under his direction that I had been carrying out my experiments on digitalis in the late Professor Douglas Maclagan's laboratory, and I used to submit myself to Dr Gamgee for experiments upon the effect of nitrite of amyl on my own pulse, from which he made sphygmographic tracings, and these experiments naturally rendered me thoroughly conversant with its physiological action on the pulse. The numerous observations I had made upon my own pulse[1] naturally made me rather expert in the use of the sphygmograph; and when resident in the Royal Infirmary at Edinburgh I made a number of observations upon a case of angina pectoris which was at that time in the wards. I found that during every attack the tension of the pulse became greatly increased, and as the pain passed off the tension fell. Every remedy had been tried in vain, and the patient was just going out of the hospital when it occurred to me that if one could lower the pressure in his vessels one would very probably relieve the pain. I therefore kept him in one day longer to try the experiment, and promised him that if it should fail he should go out next day. To my delight the experiment proved a complete

[1] Lauder Brunton "On Digitalis," Inaugural Thesis, 1866, and *Collected Papers on Circulation and Respiration*, First Series, pp. 129-136.

success. As I administered the nitrite of amyl, which my friend Dr Gamgee had given me, the patient's face became flushed, the pulse, instead of being small and thready, became full and bounding, and the pain almost instantaneously disappeared.

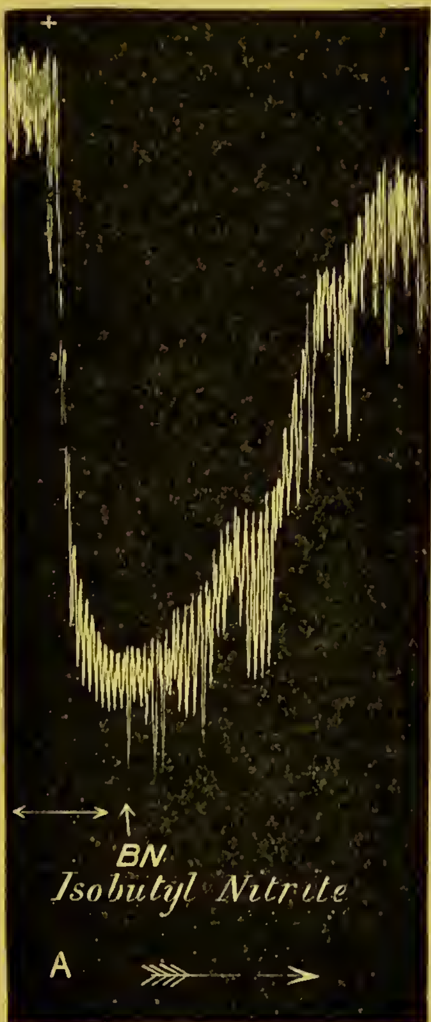


FIG. 189.—Tracing showing the action of isobutyl nitrite on blood pressure. The indications in the tracing are the same as in Fig. 190. (Figs. 189 and 190 are from a paper on "Bertoni's Ether, Amyl Nitrite, and Isobutyl Nitrite," by Lauder Brunton and T. J. Bokenham, *St Bartholomew's Hospital Reports*, 1892, vol. xxviii., p. 281.)

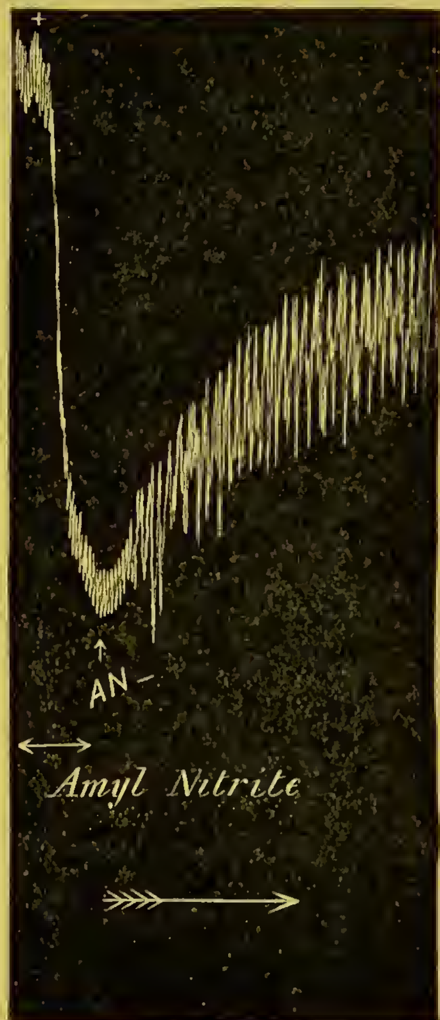


FIG. 190.—Tracing showing the action of amyl nitrite on the blood pressure. The point where the administration was begun is marked by a cross; the point where it was discontinued, by a small arrow. The horizontal double-headed arrow indicates the zero point of pressure; the single-headed arrow indicates the direction in which the tracing is to be read.

(Figs. 204-214, p. 187.) Nitrite of amyl still holds its place in medical practice as the most rapid and powerful vascular dilator, but other nitrites or nitrates having a slower but more lasting action have now come into more general use. In 1876,

along with Mr Tait,[1] I discovered that nitroglycerine had an action upon the circulation similar to that of nitrite of amyl, but I used to get such an awful headache from working with it that I hesitated to give it to patients, and while I was still hesitating Dr Murrell employed it in a case of angina with great success. It has now become the stock remedy for lowering arterial tension, and has been introduced into the British Pharmacopœia in the form of tablets containing a hundredth of a grain in chocolate. These may be either taken at once, or a little bit of them may be nibbled and the nibbling carried on until the pain passes off. If one is not sufficient, more may be used. Whilst working in Professor Ludwig's laboratory in 1869, I found that sodium nitrite had a similar action to amyl nitrite, but not so marked. This observation was not published, and the action of sodium nitrite was described some years later by Dr Hay. In 1876 and 1877 I made also a large number of experiments, along with the late Dr Gresswell of Melbourne, on the action of other nitrites, but owing to various circumstances these results also have not been published. A very interesting research by Professors Cash and Dunstan[2] on various nitrites shows that they are all alike in the nature of their action, though differing somewhat in degree. The same is the case with a substance differing entirely from them chemically, namely, hydroxylamine, which Mr T. J. Bokenham[3] and I found to dilate the vessels, and produce a fall in the blood pressure almost identical with that caused by nitrate of amyl. (Fig. 191.)

FIG. 191.—Action of hydroxylamine hydrochlorate on blood pressure.

[1] *St Bartholomew's Hospital Reports*, 1876, p. 144.
[2] Cash and Dunstan, *Phil. Trans.*, 1893, vol. clxxxiv., pp. 505-639.
[3] Brunton and Bokenham, *Roy. Soc. Proc.*, 1889, vol. xlv., p. 352.

A most interesting discussion of the drugs belonging to the nitrous group is contained in the lectures of the late Professor Leech, whose death was a loss to the whole scientific world, and a great personal grief to everyone who knew him. Nitro-erythrol is another substance which is almost more useful than any of the other nitrites, because its action, though less powerful, is more prolonged than theirs, and in cases where we wish to keep the blood pressure constantly low, it is very convenient, an eighth to half a grain or even more being taken every two, four, or six hours, more or less, as the case requires. Nitromannitol may also be used in doses of one grain or more. Where the pulse is very quick, aconite or colchicum may be given and general bleeding may be required.

LECTURE VII

Nicotine—Tobacco Smoking—Attractions of Smoking—Results of Excessive Smoking—Aconite—Local Modification of the Circulation: Inflammation—General Bleeding—Local Bleeding. TREATMENT OF CARDIAC DISEASES: Treatment of Palpitation—Diet and Regimen—Graves's Disease—Tachycardia from Strain—Paroxysmal Tachycardia.

Nicotine.—Another drug which has a very powerfui influence upon the blood pressure and cardiac action, is nicotine. Both in frogs and mammals nicotine produces, first convulsions and then paralysis. When applied in small doses to the frog's heart, it causes the beats at first to become slow and afterwards quick. If the dose be large, no primary slowing may be observed. In animals it causes slowing of the heart, with enormous rise of blood pressure. The rise of blood pressure is so great that I have never seen it equalled after the injection of any drug, with the exception of suprarenal extract. The rise of pressure is chiefly due to contraction of the arterioles. This contraction is partly dependent upon stimulation of the vasomotor centre in the medulla oblongata, but partly also to a local action upon the arterioles themselves, as it may be produced by injection of the drug even after the medulla has been destroyed. The pulse-rate in mammals is first slowed and afterwards quickened, just as in the frog. The slowing is due partly to stimulation of the vagus centre in the medulla oblongata, and partly to the stimulation of the inhibitory apparatus in the heart itself. The subsequent increase in the pulse-rate is due to paralysis of these ganglia. In consequence of this double action of nicotine, if the vagus be divided during the period of slow pulse, the pulse becomes somewhat quicker, but still remains slower than normal. When, however, the

dose has been sufficiently large to quicken the pulse, no stimulation of the vagus will slow the heart, as its terminal branches in the heart are paralysed by the drug. This action is the same in the heart of the frog, so that after a large dose of nicotine, stimulation of the vagus has no effect upon the heart, but stimulation of the venous sinus itself will slow the heart. The reason of this probably is, that, although the inhibitory ganglia in the heart are paralysed, the inhibitory neurons which proceed from them are still intact, and are affected by local stimulation.

Formerly, tobacco enemata were used as a means of causing vascular and general relaxation, but they were far from being without danger and are never employed now. But, although tobacco is not used as a remedy for disease, its employment is so universal that its action requires very careful consideration. Nicotine alone is only taken into the body when tobacco is used by chewing or by snuffing. When it is chewed, most of the juice is expectorated, but a small portion is probably swallowed. When tobacco is used in the form of snuff, small quantities of it find their way into the naso-pharynx and they are swallowed. The tobacco used for chewing or snuffing contains, as a rule, but very little nicotine, and so symptoms of poisoning from either of those habits are rare.

Tobacco Smoking.—Usually, tobacco is employed by smoking, either in the form of cigars or cigarettes, or in a pipe. When used in any one of these forms it is not pure nicotine which reaches the mouth, but really the products of the dry distillation of tobacco, containing a large quantity of pyridine and picoline bases.[1] Probably nicotine in greater or less quantity is also present. The proportions of the pyridine and picoline bases in the tobacco smoke vary according to the mode in which it is burnt. In a cigar there is a freer access of air, so that much collidine and little pyridine are formed, while in a pipe much more pyridine is produced, and thus stronger tobacco can be smoked in a cigar than in a pipe. So much is this the case, that tobacco which in the form of a cigar would

[1] Vohl and Eulenburg, *Arch. Pharm.* [2], cxlvii., 130-166. Abstracted by Lauder Brunton in *Journ. Chem. Soc.*, 1871, New Ser., vol. ix., p. 1075.

produce no disagreeable effect, may cause giddiness and vomiting if smoked in a pipe. The smoke from a pipe or cigar usually passes simply into the mouth and out again, either through the mouth or the nostrils; but when smoked in a huka or narghileh, the smoke is inhaled into the lungs, and this is frequently done also by people who smoke cigarettes. When a huka or a narghileh is used, the smoke passes through water before being inhaled, and it is thus deprived of most of its poisonous constituents; but this is not so with the smoke of cigarettes, and, as absorption occurs very rapidly from the pulmonary mucous membrane, cigarette smoking is sometimes very injurious. There is another reason, however, why cigarette smoking is frequently more harmful than smoking a pipe or cigar, and it is that cigarettes are small and can be smoked in a few minutes, so that many more cigarettes than pipes or cigars are consumed in the course of the day, and the total quantity of tobacco used is thus much greater in the form of cigarettes.

Smoking in moderation does not seem to be injurious to grown-up people, but there appears to be a general consensus of opinion that it is very distinctly harmful to growing lads.

Attractions of Smoking.—In adults, smoking appears to have a double action. It will stimulate the brain to increased

FIG. 192.—Tracing to show the increased rapidity of circulation in the carotid of a horse during mastication. (After Marey.)

activity, and it will also produce a soothing effect in conditions of excitement. Its stimulating effect upon mental activity is probably partly due to the local irritant action of smoke upon the mouth, causing reflex dilation of the vessels which supply the brain in somewhat the same way as mastication (Fig. 192).

Its action as a sedative is probably partly due to the necessity of breathing rhythmically while smoking, and the soothing effect of watching the smoke as it issues from the lips or nostrils, especially when it is blown out in the form of rings. This is by no means an unimportant factor, for many people derive but very little pleasure from smoking in the dark.

Results of Excessive Smoking.—One of the commonest results of excessive smoking is chronic pharyngitis, with irritability of the throat, cough and hoarseness, and sometimes the irritation also affects the tongue. Weakness of vision, nervous tremor, and giddiness frequently result from tobacco-smoking. It is difficult to decide how far these are due to the direct action of the tobacco smoke upon the nervous system, and how far they are caused through alteration in the circulation. The circulation becomes much affected; palpitation and pain in the cardiac region are common results. Sometimes, though rarely, the cardiac pain may be so great as to simulate angina pectoris. Irregularity of the heart is very common, and it appears to me that this irregularity is more frequently found from a common kind of tobacco known as "pig-tail" than from better-class tobaccos. When I was a house physician I met with it very frequently, and the cardiac rhythm might be represented somewhat in this way : | | | | | | | | | |

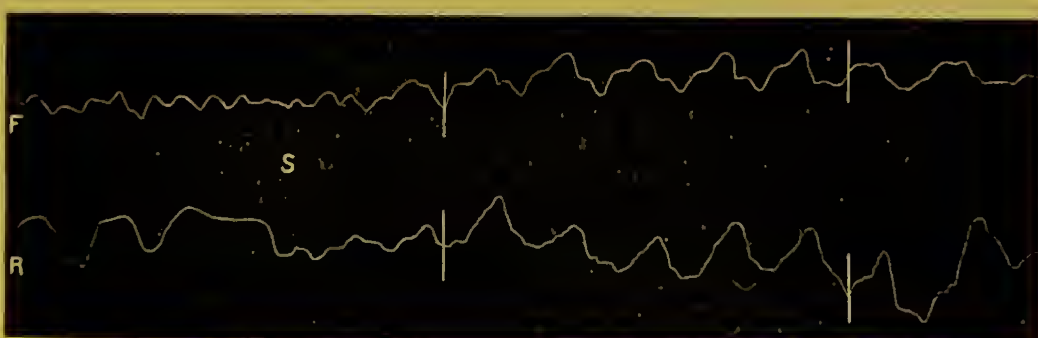


FIG. 193.—Pulsations of the fontanelle (F) in an infant six weeks old while sucking. R shows a simultaneous tracing of the thoracic respiration. The breast was offered to the child at the beginning of the tracing. At the time indicated by the third respiratory wave, which has a flattened top, the child began to take the breast. It will be noticed that the line of the tracing F rises, indicating increased circulation on the brain. (After Salathé.)

a pause, followed by one or two heavy beats, then a succession of quick, small beats, and then a pause again. With better-class

tobaccos I have not observed this irregularity so frequently, but I have more often seen the patient simply fall down unconscious, as if he had been shot. These unpleasant symptoms, as well as the nervous symptoms which accompany them, may sometimes cease upon lessening the amount of tobacco used, but not unfrequently a very small quantity appears to keep up the condition after it has once been established; and complete abstinence from tobacco, occasionally for a period of several months, is required before it can be resumed without causing a recurrence of the symptoms.

Aconite.—Aconite is a drug which may be looked upon as a typical cardiac depressant. Its most characteristic physiological action is that of causing numbness and tingling when applied to the tongue in small quantities, and this test is much more delicate than any chemical reaction. When administered to mammals in small doses, it slows the heart very greatly, and this effect is entirely due to its action upon the vagus centre. Its effects are precisely similar to those produced by stimulation of the vagus, the heart being rendered slow and the blood pressure falling. In larger doses it paralyses the ends of the vagus in the heart, so that the pulse becomes suddenly very rapid and at the same time irregular. It appears to have also a local action on the cardiac muscle, but this is of a very complex nature, and is probably connected with stimulation and paralysis of some sensory mechanism in the heart itself, to which the cardiac pulsations are partly due. That such a reflex mechanism actually exists in the heart itself appears to be shown, amongst other things, by the experiments of Von Basch and A. Fröhlich [1] upon the action of cocaine on the heart. They found that when the surface of the heart was stimulated by a Faradic current, which caused an extra beat and compensatory pause, this effect diminished rapidly when cocaine was applied to the surface of the heart. This action was not due to any effect of cocaine upon the cardiac muscle, but only to its local action on the epicardium. It is not improbable that the effect of aconite upon the heart may be due to an action upon the

[1] Von Basch and A. Fröhlich, *Centralblatt für Physiologie*, Band xviii.; *Literatur*, 1904, p. 693.

sensory mechanism in it somewhat analogous to that of cocaine. One effect of aconite is to disturb the rhythm very greatly, so that in the frog's heart the normal beats and peristaltic action may alternate.

The chief use of aconite is in local inflammations accompanied by general febrile disturbance. Small doses of this drug

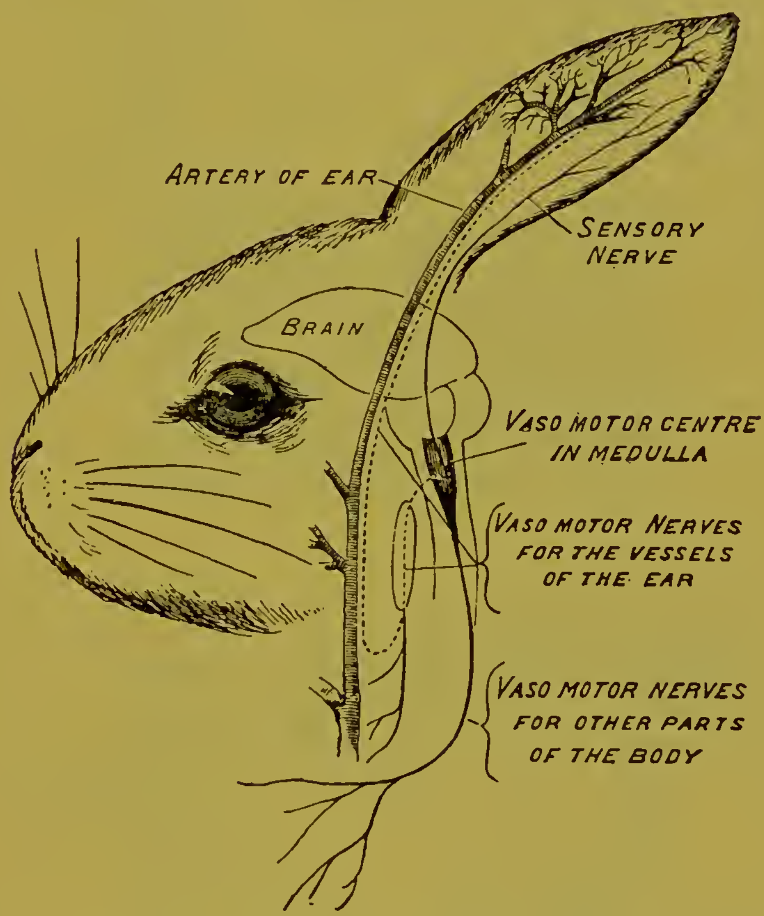


FIG. 194.—Diagram of the vaso-motor nerves of the rabbit's ear.

appear occasionally to be exceedingly useful; for example, in tonsillitis and in febrile colds. In nervous flutterings of the heart, aconite in small doses appears to quiet the circulation, but how it does so I cannot at present explain. Very small doses are sufficient, and often seem to slow the pulse more than larger ones. One minim of the pharmacopœial tincture every hour is frequently sufficient, although the dose given in the British Pharmacopœia is 2 to 5 minims, frequently repeated, or

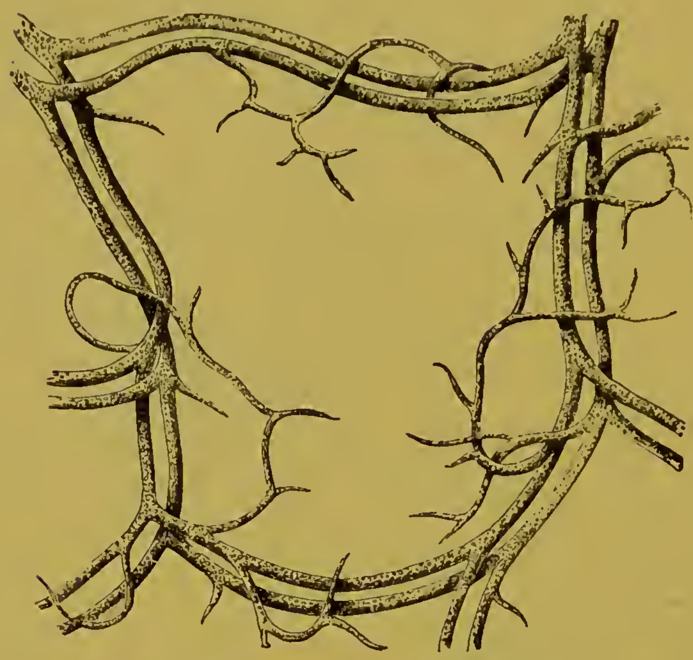


FIG. 195.—Blood vessels in normal condition. (After Lister).

FIG. 196.—Same vessels after the application of an irritant and commencement of inflammation. (After Lister).

5 to 15 minims when given at longer intervals. In cases of persistent high tension with attacks of angina pectoris, aconite is sometimes useful. Its action should be regulated by a sphygmomanometer.

Local Modification of the Circulation—Inflammation.—We have various methods of modifying the circulation locally. In local inflammations, as I have just said, aconite seems to be useful, and during its administration the local inflammation frequently subsides, the pain disappearing, the redness, swelling, and heat of the part diminishing. We may modify the local

FIG. 197.—Diagram to show the effects of heat and cold in lessening the pain of inflammation. The diagram is supposed to represent the end of the finger. The small star indicates the point of irritation, *e.g.*, a prick by a thorn. The line in the centre of each figure is intended to represent the nerve going to the injured part; and at the side of each figure is an artery and vein connected by a capillary network. In *a* the capillary network around the seat of irritation is seen to be much congested; the nerve-filaments are thus pressed upon, and pain is occasioned; *b* represents the condition of the finger after the application of cold to the arm or hand. In consequence of the contraction of the afferent arteries the finger becomes anæmic; no pressure is exerted on the nervous filaments, and pain is alleviated; *c* represents the finger after it has been encased in a warm poultice; the capillary network at the surface of the finger is dilated, and the blood is thus drawn away from the seat of irritation, and the pain therefore relieved.

circulation in inflammation either by heat or cold. If the inflammation be situated in a place where the tissues are yielding, heat frequently relieves it most, but if the tissues are unyielding, as, for example, where the inflammation occurs at the root of a tooth or under a hard fascia, heat increases the pain, while cold relieves it. The explanation of this is obvious. Heat tends to cause local dilation of the vessels, and if the nerves which run alongside them are in an unyielding sheath, the dilated vessels press more upon them and increase the pain; whereas if the tissues are yielding all round, the collateral circulation is increased, and the pressure of blood in the inflamed

area is lessened. If the nerves and vessels are both confined in an unyielding sheath, the application of cold tends to cause contraction of the vessels, and, by diminishing their calibre, to lessen pressure upon the nerves and ease the pain. The local application of heat may induce a pretty extensive dilatation of the vessels; for, on putting my feet into a bath of hot water, I have sometimes observed increased pulsation of the femoral arteries. The local application of cold in the case of an artery will cause it to contract, and lessen the circulation in the distal part; so that if a cold bandage be applied over the middle of the arm, the radial artery will beat less strongly. By putting on a cold bandage covered with oil-silk a gentle warmth of the surface is produced, which seems to have a quieting effect upon the circulation and lessens the pain from inflammation, as is evident from its use in various local lesions, and perhaps most markedly when applied to the throat in cases of pharyngitis and tonsillitis. A large wet compress of this sort applied to the abdomen is sometimes very useful in cases of sleeplessness, as it tends to draw away the blood from the brain and allow the nerve cells to become quiet. Warmth to the inside of the stomach has a similar action, and warm food will often tend to produce sleep. The food must, however, not be too warm, as otherwise the heat will pass through the diaphragm, and by its local stimulating action on the heart will increase the force of the pulse, and by driving more blood to the brain, lessen the tendency to sleep instead of increasing it.

General Bleeding.—Bleeding from the arm is a remedy which is now too little used. In the case of angina pectoris, in which I used nitrite of amyl for the first time, small bleedings of three or four ounces were the only thing which eased the pain before the nitrate was employed, and even after its employment bleeding from the arm benefited the patient.[1] In engorged conditions of the right side of the heart, whether due to mitral incompetence or pulmonary affections, blood-letting not only relieves the symptoms, but may save the patient's life.

[1] Lauder Brunton, *Clinical Society Reports*, vol. iii., 1870; and, *Collected Papers*, First Series, p. 186.

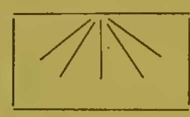
FIG. 198.—Diagram to show congestion of the lung. The pulmonary vessels are shown dilated, and those of the thoracic wall contracted.

FIG. 199.—Diagram to explain the action of counter-irritation. A blister or other counter-irritant is shown applied to the chest-wall. The stimulus which it causes is transmitted up the afferent nerves to the vaso-motor centre; it is thence reflected down the vaso-motor nerves to the pulmonary vessels, causing them to contract, while it is reflected down vaso-dilating fibres to the vessels of the thoracic wall, and probably of other parts of the body also, causing them to dilate, and thus lessening the pulmonary congestion by withdrawing blood from the lungs. (*Cf.* Fig. 198.)

FIG. 200.—Showing the effect of cold upon the arteries. A shows the normal sphygmogram from the radial artery. B is the same after the application of a cold compress above the elbow. (After Winfernitz.)

Local Bleeding.—A means of influencing the circulation locally, which was formerly much employed, but has now to a great extent fallen into disuse, is the application of leeches and cupping. The relief which is obtained by the application of half a dozen leeches to the side, in cases of severe pleurisy, is very extraordinary; and it is difficult indeed to see how the comparatively small quantity of blood which they extract should relieve the patient so much, but there can be no doubt about the fact that the relief they afford is enormous. Their application over the mastoid process in severe headache or in meningitis, and over the cardiac area in pericarditis or the liver in hepatitis, especially if accompanied with perihepatitis, is very useful. Wet cupping over the kidneys in acute nephritis and over the back in suffocative bronchitis, is sometimes attended with marked amelioration of the symptoms. It is not simply the removal of blood that produces this effect, because dry cupping, where no blood is removed, is frequently of service. In dry cupping the beneficial result may be partly due to the withdrawal of blood to the skin and subcutaneous tissue. It may also be due to a reflex effect of the stimulus upon the circulation, both local and general, and it may possibly be, to some extent, a form of serum therapeutics, as the fluid which exudes into the tissues after the application of the cups may undergo some alteration which imparts to it a curative action after its reabsorption. Any explanation of the mode of action, however, is at present hypothetical, and we are obliged to be content with knowing what the effects are without understanding how they are produced. The same may be said of the marked benefit which results from local applications over the cardiac region. When the heart is excited by emotion, the natural tendency is to place the hand over the heart, in order, as the phrase goes, "to still its beating." The pressure of the hand over the cardiac region certainly tends to quiet palpitation, and the same result is obtained, even to a greater extent, by permanent pressure from the application of a plaster over this region. The plaster may be simply adhesive; but I think the use of extract of belladonna is something more than a prejudice, and a belladonna plaster, I think, really has a

more powerful action as a cardiac sedative than a merely adhesive plaster. A good deal depends upon the way the plaster is applied. It is best not to have it too small, and in the case of women it ought to be cut like the pattern which I show you, so that it may fit over the breast. An



india-rubber bag, filled with crushed ice, applied over the cardiac region sometimes quiets excessive cardiac action; or, in place of it, a tube of india-rubber, coiled round and round, so as to form a flat plate through which cold water may be passed in a continuous stream, may have a similar action. When the action of the heart is feeble, a bag filled with hot water, or a warm poultice, a warm fomentation, or a turpentine stupe, may stimulate its action. In one case of cardiac disease I have seen ammonia liniment rubbed over the cardiac region for the relief of pain bring on such palpitation as to cause very great inconvenience to the patient, and to necessitate the relinquishing of the remedy.

Treatment of Cardiac Diseases

Treatment of Palpitation.—We may pass now from the consideration of the therapeutic means at our disposal to the treatment of definite disorders of the circulation. First of all, we may take palpitation. The first thing to be done is, of course, to try and find out its cause, and relieve it if possible. In cases where it depends upon the excessive use of alcohol, tobacco, tea, or coffee, these articles should either be diminished or, if necessary, cut off entirely. The use of a belladonna plaster I have already mentioned, and here the distinction between gentle, steady pressure and hard pressure is obvious, because, although the slight pressure of the plaster or hand tends to quiet the heart, yet the harder pressure produced by lying upon the left side frequently aggravates the palpitation, so that patients are obliged to lie upon the right side. In some cases they are obliged to lie upon their back; but, as a rule, lying on the back is disadvantageous. In many people it appears to disturb the circulation to such an extent as to cause a nightmare, frequently of such a kind as to indicate interference

with the circulation through the lungs, because the dream which makes the patient awaken is that of being chased by an animal or subjected to some other sudden strain, and when he does awake he has the same sensation of oppression, and his heart is

RECTUM AND HÆMORRHOIDAL PLEXUS.

FIG. 201.—Diagram of the veins forming part of the portal circulation. The pancreatic and splenic veins, although most important, have been omitted for the sake of clearness.

beating just as if he had been running away from a mad bull or undergoing some other violent exertion.

When palpitation depends upon distension of the stomach by flatulence pushing the heart up, and thus bringing its apex against the chest wall, immediate relief is afforded by carmina-

tives to bring the flatulence away, and I give here two prescriptions, which may serve as examples :—

℞ Sodii Bicarb.	gr. v
Spt. Æther Co.	♏v
Spt. Chlorof.	♏v
Tinct. Cardamom. Co. . . .	♏x
Aq. Menth. Pip. . . .	ad ℥j
M. mitte ℥viij	

Sig. One-eighth part to be taken alone, or with water, every ten or fifteen minutes until the flatulence is relieved.

℞ Spt. Ammon. Aromat. . . .	♏xv
Spt. Chlorof.	♏x
Tinct. Carminativ. . . .	♏x
Aqua	ad ℥ss
M. mitte ℥vj	

Sig. One-twelfth part to be taken alone, or in water, every few minutes until the flatulence is relieved..

Another useful plan is to give about one-third of a teaspoonful of sodium bicarbonate in a claret glassful of water or peppermint water, and to let the patient slowly sip as much of this as is necessary. But, in order to relieve the palpitation permanently, the digestion must be put right and fermentation in the stomach stopped. We must remember here that the blood from the stomach has to pass through the liver (Fig. 201, p. 176) before it reaches the general circulation, and that the liver and bowels require attention as well as the stomach. We very frequently are able to relieve palpitation far more by medicines which act only on the digestive canal, than by drugs which affect the heart and vessels directly. One of the best remedies that I know for functional irritation of the heart is one which my old teacher, Dr Warburton Begbie, used to call the "pulvis mirabilis." Its composition was as follows :—

℞ Bismuth Subnit. . . .	gr. x
Sodii Bicarb.	gr. x
Pulv. Nuc. Vom. . . .	gr. ss-jss
Pulv. Rhei	gr. j-iij
Pulv. Cinnamom. Co. . . .	gr. iij
M. ft. pulv.	

The great disadvantage of this powder was its filthy taste, but this can be got over by putting the nux vomica and rhubarb in a cachet, and giving the other ingredients in a mixture, along with some carminative and flavouring substance. Both the mixture and cachet are taken at the same time, and, as they mix in the stomach, one gets the effect one desires without the patient perceiving the taste. When the heart is feeble, three or four minims of tincture of strophanthus or of digitalis may be added to the mixture with advantage; and if the patient be anæmic, some preparation of iron may be either given along with, or separate from the medicine.

Diet and Regimen.—Of course, a large quantity of food which would distend the stomach mechanically should be avoided; and, if required, the meals should be small in quantity and more frequently repeated. Articles of diet that tend to cause flatulency, such as cabbage, pastry, and sugar, should also be avoided, or anything else that seems to disagree with the patient. The eating must be slow, and mastication thorough. In addition to the nature of the food, the manner in which solids and liquids are taken must be carefully attended to. When much fluid is drunk with a meal it tends to dilute the gastric juice, and this lessens digestion in the stomach, so that digestion must be finished in the intestine. When little fluid is taken with a meal the digestion in the stomach is more perfect, and consequently less digestion requires to be carried on in the intestine. People who have a tendency to flatulence should therefore take little or no liquid with their meals. But, it is evident that as the body contains so much water, water must be taken in some form or another during the day. The best form in which to take it is that of simple hot water, as hot as can be comfortably drunk, with a slice of lemon floating on the surface to relieve the insipidity of the hot water itself. The water should not be drunk in large draughts, but should be slowly sipped. The best time for taking the water is when digestion in the stomach is finished, that is to say, three or four hours after a meal. Thus, if breakfast be taken at 8, some hot water may be sipped between 11 and 12. If lunch be taken at 1, some hot water may be sipped between 4 and 5.

At this time the water may be either sipped alone or it may be slightly flavoured with tea, or the water may be sipped first and a cup of ordinary tea drunk afterwards. The water alone is best, because the cup of tea sometimes gives rise to acidity and flatulence; but its refreshing power is so great that in some cases it may be allowed, and if so, it ought to be China tea. If hot water or tea be disliked, the water may be simply flavoured with some kind of meat extract, or thin broth, julienne soup, or beef-, mutton-, or chicken-tea may be substituted, but it must not be strong. Water should again be sipped before going to bed.

Water taken in this way not only supplies the needs of the body, but it tends to wash the contents of the stomach out after each meal, so that no food is left behind to ferment. When the stomach is not cleaned out, remnants of food are apt to undergo fermentation, and the portion of each meal that is left behind tends to start fermentation in the next meal, so that a state of indigestion is set up which may remain for a length of time.

In order that digestion should be perfect the food must be thoroughly broken up, as otherwise it will not be dissolved by the gastric juice. Many people are apt to chew their food very imperfectly and wash it down with liquid, either water, tea, coffee, wine, or spirits, during the meal. When no liquid is taken with the meal, this becomes almost impossible. The food must then be broken up thoroughly and mixed with saliva. One great rule in indigestion of all sorts, therefore, is to take no liquid during meals. When liquid is drunk towards the end of a meal, the danger of imperfect mastication is lessened, but much liquid taken at this time will still interfere with digestion in the stomach, by diluting the gastric juice and so weakening its digestive power. If the patient is able to take exercise, a moderate amount of gentle exercise in the open air is advisable; and where the patient seems too weak for much exercise, massage may take its place to a considerable extent. If other means fail and the palpitation is very distressing, the patient may be put to bed and kept there steadily—regular Weir-Mitchell treatment, in fact, being adopted.

Palpitation is very apt to be associated with some disturbance in the pelvic organs, and anything wrong with these ought to be attended to, and any excitement of them should be carefully avoided.

In cases where palpitation is associated with debility, strychnine or nux vomica is of great service, and may be given as in the prescription for the "pulvis mirabilis," shortly before or after meals. Its action is complex, because it affects the whole nervous system, stimulating the brain, the medulla, and the heart. In most cases it can be borne even in large doses, but there are some where it does harm rather than good, more especially in patients of a highly nervous temperament, and where there is a tendency to excessive sensibility of the pelvic organs.

Graves's Disease.—In Graves's disease we frequently meet with very considerable palpitation, associated with excessive rapidity of the heart, and sometimes we find these conditions present without any protrusion of the eyeballs. As I mentioned before (p. 105), palpitation may be caused by a too prolonged administration of thyroid gland. The best treatment for Graves's disease is undoubtedly prolonged rest in bed, and one of the most successful cases I ever had was a lady who, luckily, became pregnant shortly after the onset of the disease. She was kept constantly in bed for nine months, and made a perfect recovery. As such patients are usually very emotional, bromides of potassium, sodium, ammonium, or strontium, either singly or combined, are often beneficial, quieting the nervous irritability and removing the restlessness and sleeplessness which sometimes are present. I have frequently used, and I think with benefit, calcium chloride, and suprarenal extract. Kocher thinks that phosphates should be given freely.[1]

Tachycardia from Strain.—Excessive exercise appears to be sometimes followed by a rapid action of the heart, which, instead of passing after the exercise is over, may continue for days or even weeks. In all probability such cases are due to a certain amount of cardiac strain, and ought to be treated as such.

[1] Common salt in drachm doses, with plenty water, three times a day is sometimes useful.

Paroxysmal Tachycardia.—In paroxysmal tachycardia, the beats of the heart, which may previously have been perfectly normal, suddenly become excessively rapid, as much as three or four times as quick as before. It would almost seem

FIG. 202.—Case of exophthalmic goitre, *St Bartholomew's Hospital Journal*, December 1897.

in these cases as if each cavity of the heart was capable of giving an independent stimulus to the contraction of the whole, so that a pulse of 60 might suddenly jump up to a pulse of 240. We do not know the pathology of such cases, but they are not unfrequently associated with a certain amount of fatty degenera-

tion in the heart. They are benefited during the attack by cold applications over the heart, sometimes by drinking iced water, so as to get the effect of cold directly upon the heart through the stomach, and sometimes by a powerful stimulant such as strong coffee. The attack may sometimes be cut short by the administration of an emetic such as 20 grains of sulphate of zinc, or mustard and water may be employed. During the interval, small doses of strophanthus, digitalis, strychnine, and eserine may be useful in steadying the heart. If they are associated with high tension, vascular dilators must be employed; and if they occur in gouty people, the diet should be, to a great extent, non-nitrogenous. In some cases the attack of tachycardia appears to be due to reflex irritation from the stomach, and bismuth, sodium bicarbonate, pepsin, or other digestive ferments are of service by lessening dyspepsia, while bromides diminish reflex irritability, and dilute hydrocyanic acid acts as a local gastric sedative. Time will not allow me to enter fully into the physiological action and uses of these drugs, and I must refer any one who wishes to study them more completely to my Text-Book of Pharmacology.[1]

[1] *A Text-Book of Pharmacology, Therapeutics, and Materia Medica.* Macmillan & Co., London, 1893.

LECTURE VIII

Bradycardia—Stokes-Adams Syndrome—Irregularity of Pulse—Angina Pectoris—Treatment of an Attack of Angina Pectoris—Diet and Regimen in Angina—Cardiac Asthma—Sleeplessness—Aortic Disease—Mitral Regurgitation—Nauheim Treatment—Oertel's Treatment—Treatment of Venous Stasis—Graduated Exercises—Elimination—Milk Diet—Chloride-free Food—Tapping—Surgical Treatment of Cardiac Diseases—Senile Rise of Pressure—Senile Decay—Prolongation of Life.

Bradycardia.—The opposite of tachycardia is brachycardia, or, as it is often termed, bradycardia. In some cases of brachycardia the slow pulse is associated with syncope. This condition is known by the name of Stokes-Adams syndrome. In these cases the patient is affected sometimes as much as three or four times a day by giddiness, insensibility, or epilepsy, and this condition is probably due to atheroma of the vessels in the medulla. In some people the pulse is naturally very slow. In Napoleon, as I have remarked, it was said to have been only 40 per minute, and in a fellow-student of mine was only 42 per minute. This man came from Demerara, and I do not know whether malarial affection had anything whatever to do with it or not. Extreme slowness of the pulse is probably due to excessive action of the inhibitory nervous mechanism, either in the medulla oblongata or in the heart itself. Sometimes the latter may be excited by irritation of the vagus trunks or branches of the vagus in the cardiac plexus, just as slowness of the pulse may be produced experimentally by irritation of the vagus in animals. Slowness of the pulse sometimes occurs in women after childbirth, but the explanation of it is uncertain. It is very apt to occur when the heart is feeble, as during convalescence from infective

diseases, such as acute rheumatism, diphtheria, pneumonia, and typhoid fever; in general weakness due to anæmia, chlorosis, and diabetes; and in permanent weakness of the cardiac walls due to fatty or fibroid degeneration. It is seen also in typhoid fever even while the temperature is high, and in this case it is probably due to the effect of a toxin which stimulates the inhibitory mechanism either in the medulla or the heart, and prevents the pulse from rising above 96 even when the temperature would lead one to expect a pulse of 120. In the convalescence from diphtheria the slowness of the pulse is not improbably due to

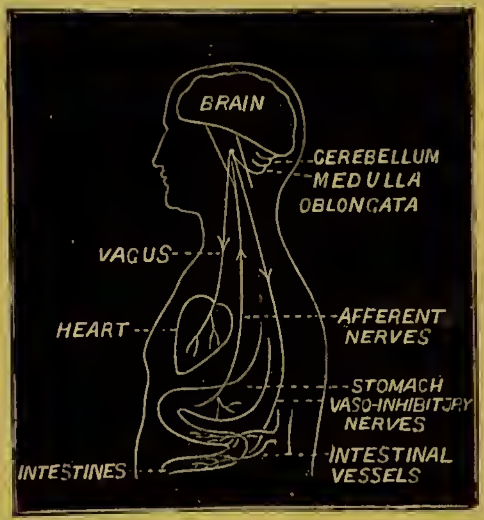


FIG. 203.—Diagram to show the nervous mechanism by which the action of the heart may be depressed by irritation of the stomach. The reflex irritation of the vagus may render the heart's action simply weak, or slow and weak.

some neuritis of the vagus, which, in severe cases, leads to complete paralysis with exceedingly rapid pulse. Other poisons, such as those which occur in uræmia, and also alcohol, coffee, digitalis, lead, and tobacco, may cause a very slow pulse. It is frequent in jaundice, and its occurrence here appears to be due to the bile acids which weaken the cardiac muscle and render it more easily affected by the inhibitory nerves.[1] The medullary centre of the vagus may be stimulated and a slow pulse produced reflexly from the stomach, as in dyspepsia, cancer, or ulcer, from the intestines, or from the skin or sexual organs. (Fig. 216.) It occurs also when there is pressure within the

[1] Wickham Legg, *Bile, Jaundice, and Bilious Disorders*, London.

cranium, as from cerebral abscess, aneurysm, hæmorrhage, or tumour; in meningitis, either simple or tubercular; in epilepsy, general paresis, mania, sunstroke, melancholia, and injuries of the medulla or cervical cord. It is also brought about when the pressure which the heart has to overcome is abnormally high, either in the pulmonary circulation, as in emphysema, or in the general circulation, as in chronic interstitial nephritis. The variety of causation is so great that the treatment is necessarily very different in many of those cases. Speaking generally, however, we have to remove the cause as far as it is in our power. If due to toxins, we must try to lessen their formation in the stomach and intestines by the use of antiseptics and by free purgation, more especially by the use of mercurial purgatives and salines, so as to clear out the bile, in which toxins are largely contained. Where the slow pulse is due to reflex inhibition from the stomach, we must remove the source of irritation and lessen the reflex excitability of the vagus centre. We may do this by the use of alkalies and bismuth to soothe the gastric mucous membrane, and bromide of potassium to lessen the nervous irritability.[1] In all cases it is advisable to try to strengthen the heart itself, and nux vomica or strychnine with iron are amongst the most useful remedies for this purpose.

Irregularity of Pulse.—Alterations in the rhythm of the heart, alternating tachycardia and brachycardia, so as to give an irregularity or intermittence, are usually due to a combination of the causes that produce either the one or the other. In poisoning by digitalis, for example, we get in its various stages brachycardia, irregularity, and tachycardia, *vide* p. 109. According to one explanation, this occurs as the inhibitory apparatus is stimulated, or has begun to suffer from more or less complete paralysis. According to another, it depends on the rate of production and conduction of stimuli in the heart itself. The treatment of irregularity and intermission is, therefore, much the same as that for tachycardia and brachycardia. An irregularity of the pulse may sometimes persist for years.

[1] *Vide* Author's remarks on a case by Dr Somerville, *Practitioner*, vol. xvi., p. 186.

One patient of mine, who is now seventy-nine years of age, had a bigeminal pulse, that is, two beats in rapid succession followed by a longer pause, for many years. He is still hale and healthy. A relative of my own died at the age of eighty-four, after having had a very irregular pulse for sixty-seven years. This irregularity of the pulse came on after an attack of rheumatic fever at the age of seventeen, and continued all the rest of her life.

Angina Pectoris.—One of the most distressing forms of cardiac disturbance is angina pectoris. I have already mentioned the relationship between this disease and diminished circulation through the coronary arteries, as well as the probable causation of the pain. In many cases this is situated about mid-sternum, but it is frequently felt more towards the cardiac apex, and often radiates towards the shoulders and down the arms, especially the left arm. As I have already said, it is probably due to a want of relationship between the power of the cardiac muscle and the resistance it has to overcome. It is brought on by anything that raises the blood pressure quickly, such as exertion or emotion, and especially by the emotion of anger, which, as in John Hunter's case, may bring about a fatal attack at once. Anything that interferes with the action of the heart tends to increase the pain, and thus distension of the stomach by tilting the heart up makes the patient worse, and much relief is afforded by the administration of carminatives, which bring the flatulence away and allow the heart to resume its normal condition.

During the process of digestion the blood pressure tends to be higher than usual, and immediately after digestion pain is brought on by the slightest exertion with much greater ease than during the fasting condition.

Treatment of an Attack of Angina Pectoris.—The indication for treatment, of course, is to relieve the heart by dilating the vessels, and this is brought about most quickly by the use of nitrite of amyl.[1] Nitrobutyl and other organic nitrites have a similar action, but nitrite of amyl seems, upon the whole, to be

[1] Lauder Brunton, *Lancet*, July 27, 1897, and *Reports of the Clinical Society*, vol. iii., 1870.

Fig. 204.—Normal pulse, right radial.

Fig. 205.—Normal pulse, left radial.

Fig. 206.—Right radial, during angina.

Fig. 207.—Left radial.

Fig. 208.—During severe anginal pain.

Fig. 209.—Pain nearly but not quite gone, a little remaining near the nipple after giving nitrite of amyl.

Fig. 210.—Pain quite gone, but afterwards returned.

Fig. 211.—Pain quite gone, which did not return.

Fig. 212.—Pain coming on at 1, more severe at 2. Most severe at Fig. 213.

Fig. 213.—Pain severe.

Fig. 214.—Pain relieved by nitrite of amyl.

Figs. 204 to 214.—Tracings of the pulse in angina pectoris.

the most satisfactory. Nitroglycerine acts nearly, though not quite so quickly, and is more convenient. It has also the advantage of dilating the vessels for a longer time than nitrite of amyl. It may be given in solution with a little brandy or ether, or the patient may carry about with him nitroglycerine tablets, each containing one-hundredth of a grain, made up with chocolate; and the best plan, as a rule, is not to swallow the whole tablet, but to nibble it slowly until the pain has ceased. If half a tablet is sufficient, it is not necessary to take more; but if one is insufficient, then as many more may be taken as are necessary. I have never seen any bad effect from an overdose either of nitroglycerine or amyl nitrite, except headache, giddiness, or transient faintness. When the attack is excessively severe a neuralgic element may be superadded to the physical condition, and I think it is possible that sometimes it may come on independently. At any rate, a subcutaneous injection of a quarter or a third of a grain of morphine may sometimes be necessary, in order to lessen the pain and give the patient relief, and a few whiffs of choroform will deaden the pain until the morphine has had time to take effect.

Diet and Regimen in Angina.—During the interval the tension should be kept low by diet as nearly as possible vegetarian, taking care that it is easily digested and that it does not give rise to flatulence. Tea and coffee, and, of course, all meat extracts which contain substances of the purin type and tend to raise the blood pressure, should be avoided. The bowels should be kept freely open, and mercurials should be given, once, twice, or three times a week at night, followed by a saline in the morning, so as to remove from the body all substances likely to raise the blood pressure. Many substances having a poisonous action are absorbed by the liver and excreted in the bile. They are reabsorbed from the duodenum, again passed to the liver, and again excreted. (Fig. 215.) This may go on for a long time in the entero-hepatic circulation, until they either accumulate to such an extent that they pass into the general circulation and act upon the nervous system, heart, or other organs, or are cleared out by mercurial purgatives and salines. Nitro-erythrol in doses of

half a grain three times a day, or more if required, will sometimes keep a patient, who would otherwise suffer from angina pectoris, perfectly comfortable for years.

All such persons, however, should take care to remain quiet for half an hour at least after every meal, and when they get up

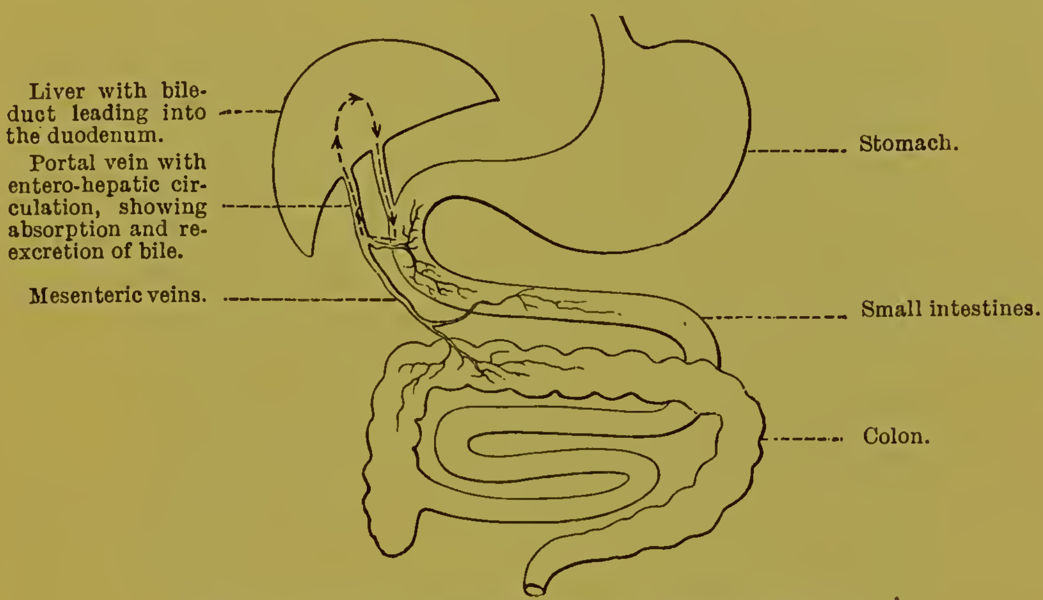


FIG. 215.—Diagram to illustrate the entero-hepatic circulation.

they should move very slowly until they begin to get warm. When the vessels of the muscles become dilated, patients are frequently able to walk with perfect comfort even at a rapid pace. *Cf.* Influence of muscular area, p. 15.

Cardiac Asthma.—When the right side of the heart is enfeebled the symptoms of cardiac asthma are apt to come on. The patient is quite comfortable so long as he remains still, but the least exertion brings on rapid breathing, or even dyspnœa and distress. This condition is largely due to degeneration of the right side of the heart, consequent upon interference with the circulation in the right coronary artery. It may be associated with fatty degeneration of both sides of the heart, but it may also occur in the right side independently of the left.[1] Nitrite of amyl is not of so much use in this as in ordinary angina, as the pulmonary circulation does not seem to be affected by nitrites to the same extent as the general

[1] Lauder Brunton, *Practitioner*, June 1905.

circulation. Inhalation of 5 minims of iodide of ethyl is sometimes serviceable, but inhalation of oxygen occasionally affords very great relief, and in a case which I recently saw the tension in the radial artery rose under the influence of oxygen to an extent which I should not have believed if I had not seen it. The tension, as tested by Potain's instrument, was only 75 when the inhalation was begun, and in the course of ten minutes' inhalation it rose steadily until it had reached 150.

In cardiac asthma gentle exercises are useful as tending to train the heart, increase its nutrition, and thus accelerate the circulation through the lungs. At the same time, iodide of potassium, strychnine, digitalis, squill, and strophanthus are all useful, as well as Oertel's treatment, which we shall presently have to consider in relation to valvular disease.

Sleeplessness.—Although sleeplessness may occur apart from any disease of the heart, yet it not infrequently occurs along with cardiac disease, and forms one of its most distressing symptoms. In many cases the patient is intensely drowsy, but the moment he falls asleep he feels a sensation of intense distress, and awakes with a start. Sometimes this condition appears to be aggravated by flatulent distension of the stomach, or acidity, and it may be somewhat relieved by the use of bicarbonate of soda and carminatives, alone or with rhubarb. A purely milk diet for some days may also be useful. The various hypnotics may all be tried. Paraldehyde is sometimes efficacious in drachm doses, trional or sulphonal in 20 or 30 grain doses, and chloral 10-30 grain doses, with bromides of potassium, sodium, or ammonium, or all three mixed, in doses of 30-60 grains. As chloral has a somewhat depressing action on the heart, one may hesitate to give it if the cardiac action is very weak, but this very action, by lowering the blood pressure, increases its hypnotic effect. The remedy *par excellence* in this condition, however, is opium or morphine. The latter may be given either by the mouth or subcutaneous injection, and the former either by the mouth or rectum. A convenient way is to draw 30-60 minims of tincture of opium into a glycerine syringe holding 2 drachms, then draw up

water till the syringe is full, and inject into the rectum. The advantage this method has over administration by the mouth is that one can be quite sure beforehand that the rectum is empty and that absorption will take place quickly, whereas the stomach may contain a large quantity of food or fluid with

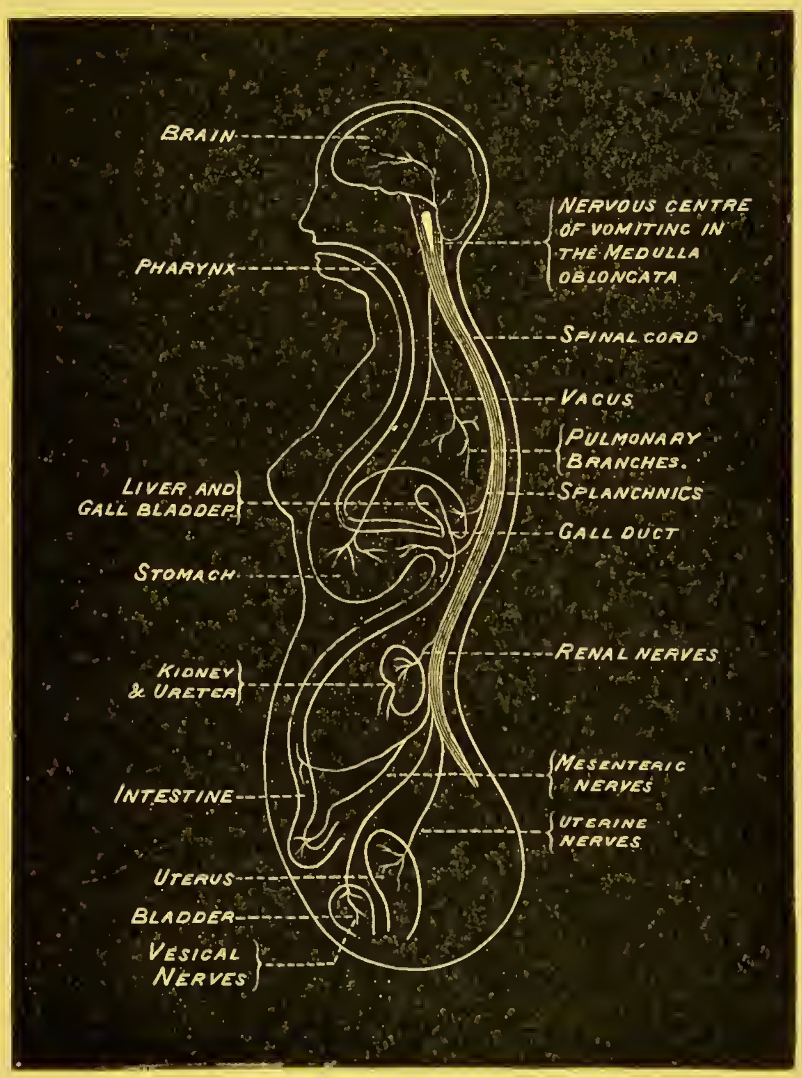


FIG. 216.—Diagram showing the afferent nerves by which the vomiting centre may be excited to action.

which the opium will be so much diluted that it may have hardly any effect. Sometimes neither opium nor morphine seem to produce the desired effect, even when given in full doses, and in such cases a few whiffs of chloroform may be given so as just to allow the narcotic to take effect. And here

it may be well to say that I do not think the presence of albumen in the urine contra-indicates the use of either opium or morphine. The susceptibility of patients to these drugs varies so much that it is impossible to fix a dose, but usually one may begin with $\frac{1}{6}$ or $\frac{1}{4}$ of a grain of morphine subcutaneously, and increase the dose carefully until the desired result has been obtained. Even should there seem to be danger in pushing the narcotic, it must be remembered that to withhold it also entails risk, for the exhaustion of the patient by continued insomnia cannot but tend towards a fatal termination.

Aortic Disease.—As I mentioned before, cases of aortic stenosis or aortic regurgitation may continue for a length of time without giving rise to any symptoms whatever, and are recognised only by a systolic murmur over the aorta in the case of the former, and a diastolic murmur in the case of the latter. Here I think I ought to give a word of caution as to the place where the aortic regurgitant murmur is heard. It is usually heard quite markedly over the aortic valves, or perhaps I ought to say rather over the aortic cartilage, and is propagated down the sternum, but sometimes is not heard at all at the base of the heart, and is only audible at the lower end of the sternum, more especially to its left side. This condition was impressed upon me by the fact that an old friend of mine in Edinburgh told a lady that she had aortic regurgitation. She came up to London and saw the late Sir Andrew Clark, who told her there was nothing the matter with her heart. She went back to Edinburgh and rebuked my old friend very severely for having frightened her unnecessarily. He said he was sorry, but nevertheless she had aortic regurgitation, and if she would go back and ask Sir Andrew to examine her

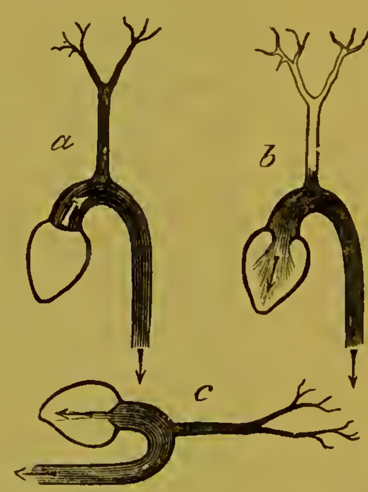


FIG. 217.—Diagram to illustrate the occurrence of syncope in cases of aortic regurgitation. In *a* the normal heart with full carotid and free supply of blood to the brain is represented; in *b* the carotid is shown empty, so that syncope will occur from blood flowing back into the ventricle as well as onward into the aorta; in *c* is shown aortic regurgitation in the recumbent posture, so that the carotid is well filled and regurgitation into the heart is rather less.

more carefully, he would find it too. She did so, and on the second examination Sir Andrew found the murmur as my friend had described it, and wrote to him acknowledging his error. Now, no one could possibly doubt the great clinical knowledge and exact diagnosis of Sir Andrew Clark, and the reason that he fell into error was simply that his waiting-room was filled with patients, and in order to save time he did not ask the lady to loosen her stays. On listening over the part of the chest above the stays, no murmur was audible, and it was only after the stays were removed that the diastolic murmur at the lower end of the sternum could be distinguished.

Persons suffering from aortic regurgitation are more liable to sudden death than those suffering from any other form of cardiac disease, except, perhaps, those who have angina pectoris; but so long as the valvular lesion is fully compensated, all that is necessary is to warn the patient against sudden strain. Many of them might walk 25 miles in a day without harm, or even with positive advantage, but 20 yards sudden spurt to catch a train might prove fatal. Although sudden death occurs not infrequently in aortic regurgitation, yet perhaps a still more frequent course of the disease is for the left ventricle to yield before the strain, and then the mitral valves become incompetent, so that we get all the consequences which I have previously described from backward pressure on the lungs and right heart. In uncomplicated cases of aortic regurgitation, digitalis is likely rather to add to the danger they already incur from syncope than to do the patients good. In some cases, however, if carefully watched, it may tend, especially when combined with strychnine and caffeine, to keep the left ventricle from yielding, and thus maintain the patient's health.

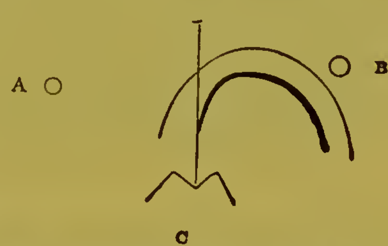


FIG. 218.—Diagram of the cardiac dulness before and after a bath. A similar effect is produced by gymnastic exercises. The thin line shows the graduated dulness before and the thick one after. A, Nipple. B, Nipple. C, Ensiform cartilage. (After Schott.)

But in cases where the ventricle has already dilated and the mitral valves become incompetent, we have to treat the

patient just as we would an ordinary case of mitral disease, for the danger then arises from impeded pulmonary circulation and venous stasis rather than from imperfection of the general circulation. Such cases, however, as a rule require to be

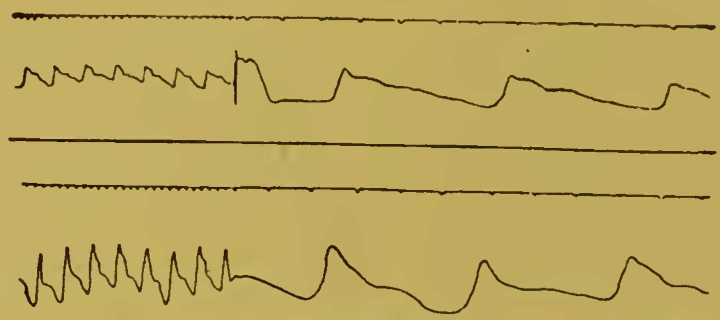


Fig. 219.—Pulse tracing, showing the effect of massage and graduated movements. Each tracing is taken partly with a slow and partly with a quick movement of the sphygmograph. The upper shows high tension and a feeble heart; the lower shows less tension and a stronger heart. These tracings I owe to the kindness of Dr Gustav Hamel, to whose treatment I had recommended the patient.

treated rather as cases of advanced mitral disease, with complete rest, than as mild cases where the patient may be allowed to go about.

Mitral Regurgitation.—Mitral incompetence is much more

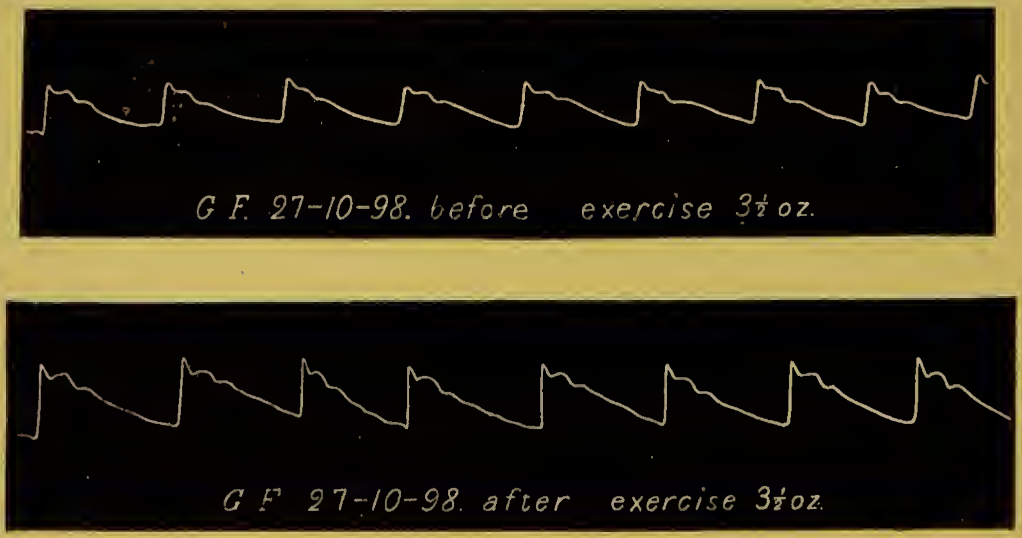


Fig. 220.—Pulse tracing to show the effect of exercises. The upper tracing shows the pulse before, and the lower tracing after exercise.

frequent than is usually thought, for people go about with slight mitral leakage and present no symptoms, so that the condition

of the valve is only discovered by a medical examination. These patients are usually told, and rightly so, not that they

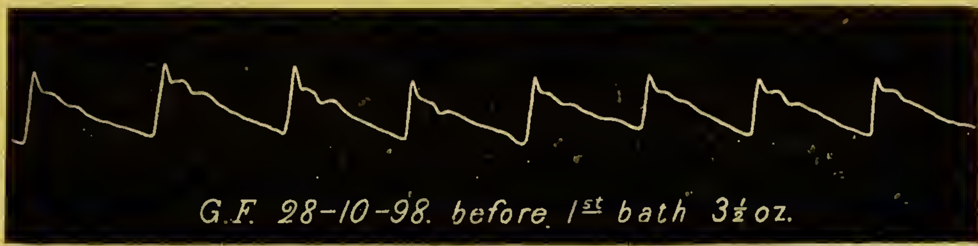


FIG. 221.—Tracing from the pulse of a patient aged 62, with gouty kidney, of a failing heart. This tracing and the three following show the effect of Nauheim baths in increasing the cardiac force and dilating the vessels.

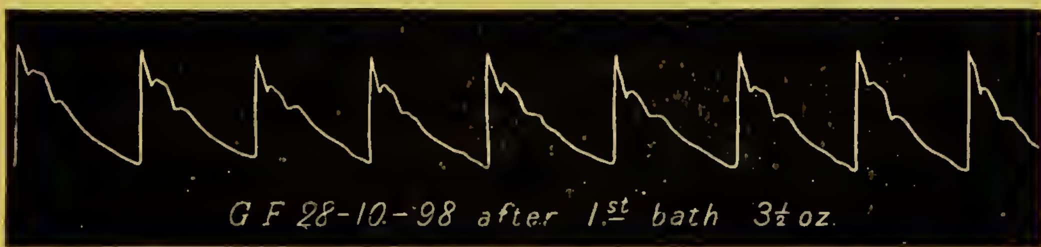


FIG. 222.—Effect of one bath.

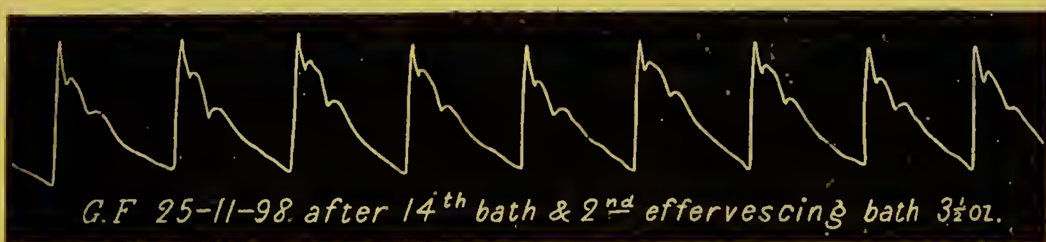


FIG. 223 —From the same patient.

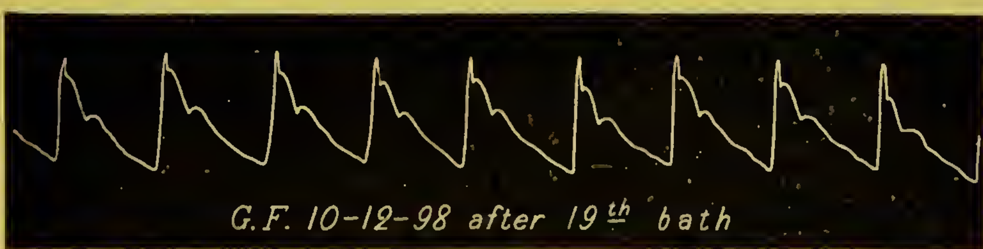


FIG. 224.—From the same patient, after nineteen baths.

have any disease of their valves, but that their heart is a little weak, and they must be careful to avoid strain. As a general rule, this is all that is necessary; but when shortness of breath

or symptoms of venous stasis set in, more active treatment is required, and here digitalis and strophanthus find their proper place.

Nauheim Treatment.—For such cases also the treatment by baths and exercises is useful. The system of applying them has been well worked out by the brothers Augustus and Theodore Schott, at Nauheim, and the treatment is often known now as the "Nauheim" treatment. At Nauheim, the water as it issues from the springs is very highly charged with carbonic acid, but this is allowed to escape, and the water to become still, for the baths which are given at first, and it is only in the later baths that the effervescent water is employed. Baths are usually employed every other day during a course of four to six weeks, or even longer, according to the condition of the patient. The bath at first lasts only about six minutes at a temperature of 95. The duration is then increased to eight or ten minutes, and the temperature is lowered to 92. They are then strengthened further with the mother liquor obtained by evaporating the ordinary water. The duration is gradually increased to fifteen or twenty minutes and the temperature lowered as far as 82. Immediately after the bath the patient must rest for at least an hour, and on alternate days movements may be used. I give here a list of the movements, which Professor Schott at Nauheim kindly got his attendant to show me:

The essential part of these movements is that the movement shall be slow and regular, and that each movement shall be fully carried out. The body should be held upright, the joints should be kept straight, and the resistance applied should not be sufficiently great to cause any tremor of the limbs or shortness of breath in the patient. The resistance may either be applied by the patient himself putting into action the opposing muscles to those which affect the movement, or by an attendant or friend gently opposing the movements.

I. The arms are to be raised slowly outwards from the side until they are on a level with the shoulder. After a pause they should be slowly lowered.

II. The body should be inclined sideways as much as possible towards the right, and then to the left.

III. One leg should be extended as far as possible sideways from the body, the patient steadying himself by holding on to a chair. The leg is then dropped back. The same movements are repeated by the other leg.

IV. The arms are raised in front of the body to a level with the shoulder, and then put down.

V. The hands are rested on the hips, and the body is bent forwards as far as possible, and then raised to the upright position.

VI. One leg is raised with the knee straight forwards as far as possible, then brought back. This movement is repeated with the other leg.

VII. With the hands on the hips, the body is twisted round as far as possible to the right, and then again to the left.

VIII. With the hands resting on a chair and the back stiff and straight, each leg is raised as far as possible backwards, first one and then the other.

IX. The arms are extended and the fists supinated. The arms are then extended outwards, next inwards at the height of the body.

X. Each knee is first raised as far as possible to the body, and then the leg extended.

XI. This movement is the same as IX., but with the fists pronated.

XII. Each leg is bent backwards from the knee and then straightened.

XIII. Each arm is bent and straightened from the elbow.

XIV. The arms are brought from the sides forwards and upwards, then downwards and back as far as they will go, the elbows and the hands being straight.

XV. The arms are put at a level with the shoulder, and then bent from the elbow inwards and again extended.

XVI. With the arms in front at the level of the shoulder and the hands stretched, the arms are opened out sideways and then brought together.

XVII. The arms are bent from the elbow outwards and extended.

*** There should be a pause of half a minute between each successive movement, such as raising the arms and lowering them, and a pause of one or two minutes between the movements of different kinds, such as I. and II.

After the course is over it is advisable for the patient to go some place for an after-cure, where he can follow up the treatment by graduated exercise.

Oertel's Treatment.—This treatment by graduated exercise is often known as Oertel's. The principles upon which it depends are—(1) that the cardiac symptoms are due to disproportion between the force of the heart and the resistance it has to overcome; and (2) this disproportion is to be remedied by dietetics and by exercise, consisting chiefly of graduated walking uphill.

The dietetic rules are—(1) Give such food as will strengthen the cardiac muscle; and (2) diminish the amount of liquid consumed, in order to reduce the mass of circulating blood.

The exercises are intended to promote elimination of liquid, especially through the lungs and skin, and to increase the nutrition and activity of the heart. In aortic regurgitation, Dr Schott considers that the work of the heart is easier when there is abundance of blood to make up for the loss in the general circulation sustained by regurgitation during the diastole. He, therefore, advises a very full diet; but in mitral disease, where the patient, on account of breathlessness, can move less than a healthy person, he advises a sparing diet. In chronic myocarditis, where albumen is required, but not nuclein, butcher's meat should be given sparingly, but milk and plasmon freely. In aortic disease he allows two pints of fluid a day, and as much as three pints if the weather be hot; but if there is any interference with the pulmonary circulation, as shown by shortness of breath, he only allows between a pint and a half and two pints. In mitral disease he only allows about a pint and a quarter to a pint and a half.

The exercise consists in gentle walking up graduated slopes. The first walk is taken upon a very gentle slope, and only for a short distance. This is increased daily, and when the patient can walk on the level or gentle slope without shortness of breath he walks up a somewhat steeper grade. The steepness is gradually increased as the patient's heart will bear it. Such walks have been well arranged at Llangammarch in this country, and one of the best places abroad is, I think, Badenweiler, although there are numerous other places where similar walks have been laid out.

Treatment of Venous Stasis.—In cases of well-marked venous stasis, whether it be dependent upon mitral stenosis or regurgitation, or dilatation of the right side of the heart consequent upon bronchitis and emphysema, the best results are certainly afforded by *complete rest*, in bed if possible, or in a chair if the dyspnœa be so great that the patient cannot stay in bed. In such cases massage comes in most usefully, the hand of the masseur or masseuse supplying, as it were, the place of an auxiliary heart in helping the venous return, and the place of the lymph hearts which we find in batrachians (*cf.* p. 5).

Graduated Exercises.—Gentle movements are also useful; for example, the patient may bend one finger gently against resistance the first day or even the first forenoon. In the afternoon he may straighten the same finger against resistance. Next day he may bend two fingers, and in the afternoon extend two fingers and so on, gradually including the wrist, the fore-arm, and even the arm. The resistance should at first be very slight indeed, and may be gradually increased as the patient can bear it. Such gentle movement as simply flexing a finger might seem at first sight to be useless, but if any of you will put your hand upon your biceps and get someone else to hold your finger while you flex against resistance, you will soon discover that it is not merely the muscles of the finger alone that are in action, but that the biceps, and even the muscles of the trunk take part in the movement. The effect of massage and exercises on the pulse is shown by the tracing in Fig. 219, where the high tension with slight movement of the radial artery is converted into less tension, quicker contraction of the heart, and more active movement of the vessel increasing the self-massage both of the arteries and the heart.

Inhalation of oxygen certainly gives great help in some cases, and I think it is possible that occasionally the deep inhalations which patients take when they are inhaling the oxygen may help mechanically by producing self-massage of the heart.

Elimination.—I have already spoken of the action and use of digitalis and its congeners as well as of caffeine in such cases, and have given you the indications for employing them, and also referred to the symptoms which necessitate their discontinuance. But here, again, you must remember that the imperfect circulation and imperfect respiration tend to produce the products of waste, and we must look to the elimination of these by means of purgatives such as calomel and compound jalap powder. Half a drachm to a drachm of compound jalap powder every morning, or every other morning, is a most useful agent in withdrawing water from the body, and thus aiding the action of the kidneys, especially when ascites is present. Its

efficacy is, I think, increased by the addition of a drachm of potassium bitartrate to every dose. Another well-tried remedy is the Haustus Scoparii Compositus of St Bartholomew's Hospital. Its composition is as follows:—

Spirit of Juniper	30 minims
Potassium Tartrate	20 grains
Decoction of Broom Tops . . .	to 1 ounce

The action of mercurials is not properly understood, but it is very curious to note how frequently the addition of a little mercury to digitalis increases its beneficial action. The old-fashioned pill of one grain of powdered digitalis, one of powdered squill, and one of blue pill, frequently succeeds when other remedies fail. At St Bartholomew's we have two grains of extract of hyoscyamus added to this pill, in order to lessen any irritation of the stomach or bowels that the other ingredients might produce; whilst in other hospitals the quantity of squill and blue pill is increased to two grains and the amount of digitalis is kept at one grain.

Milk Diet and Chloride-free Food.—Lately a great deal of attention has been given, especially in France, to the effect of chlorides upon transudation from the vessels into the tissues. Chlorides appear to favour this, and therefore, although they may be useful in health, they are disadvantageous in dropsy, and accordingly a diet containing a small quantity of chlorides is used. Calcium and its salts appear to have a contrary action, and rather to diminish transudation. The amount of chlorides in milk is not great, the quantity of calcium is considerable, and the lactose appears to have a diuretic action; so that frequently we notice patients suffering from mitral disease when put to bed with entire rest, with massage, with an entirely milk diet, just as if they were typhoid patients, and with the digitalis and blue pill already mentioned, frequently improve with great rapidity. But a milk diet does not always suit; and consequently, in France, bread made with sugar instead of salt, farinaceous preparations also made with sugar and without salt, and boiled meat without salt, but with sweetened tomato sauce or some such condiment to make it pleasant, and eggs, either boiled without salt or in the form of a sweet omelette,

and plasmon, may all be used. I have only tried this in a few cases, but certainly the treatment has appeared satisfactory.

Tapping.—When the œdema becomes very great in the legs or scrotum, it is advisable to let it out, and the way in which this can be done depends to a great extent upon the character of the patient. In some, Southey's or Bartel's tubes may be used to drain the legs or scrotum, but when the patient is restless these are apt to be dragged from their place, and almost the only way is to puncture the legs either with an ordinary sewing needle or with a triangular surgical needle, or make small incisions with the lancet or bistoury, and surround the parts with absorbent cotton wool, which can be frequently changed, and place a waterproof sheet under the part to prevent the bed from becoming soaked. Effusion into the serous cavity of the abdomen or pleura must be removed by tapping, if it reach any great extent.

Surgical Treatment of Cardiac Diseases.—In some cases of cardiac disease treatment may for a time be beneficial and relieve the patient's sufferings, but may be quite impotent to effect a cure or to render the patient fit for any exertion whatever. This is especially marked in mitral stenosis, and I believe that in some cases of this form of cardiac disease surgical treatment may yet effect a cure.[1]

Senile Rise of Pressure.—I must not finish my Lectures without drawing attention to one condition which is very common, and which may become still commoner as increasing medical knowledge regarding the prevention of infective disease leads to prolongation of life. In all men with advancing years the arteries tend to lose their elasticity and become more rigid. The time at which this alteration takes place varies in different individuals and in different families, and the saying is a particularly true one that "a man is as old as his arteries"; so that not infrequently we find strong athletic and robust families who are not only powerful both physically and mentally, but apparently free from disease, and who are yet short-lived. I believe that these lives might frequently be

[1] Lauder Brunton, "On the Possibility of Treating Mitral Stenosis by Surgical Methods," *Lancet*, 8th February 1902.

lengthened by timely attention to the condition of the arteries, more especially by measurement of the blood pressure, and adjustment of work, of exercise, and of food to the condition

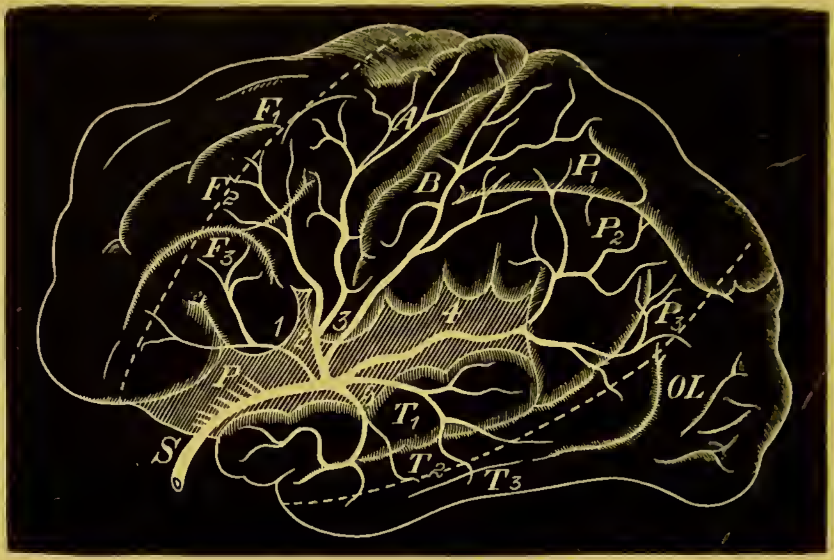


FIG. 225.—Distribution of the arteries in the brain. (After Ross.)

that is found. The combination of atheromatous arteries and high blood pressure is very common, and the risks it entails are twofold: (1) It may lead to cardiac failure, the heart being

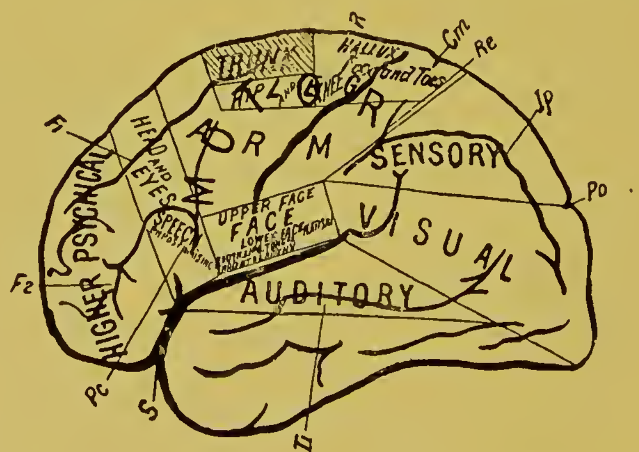


FIG. 226.—Cerebral cortex showing the distribution of function. (After Osler.)

unable to overcome the excessive tension, and this is all the more common when it is affected by fatty or fibroid degeneration; (2) a vessel may rupture in the brain, and give rise to

sudden death, to hemiplegia, or, if the hæmorrhage be small, to local paralysis, sensory affections, or mental deterioration, the result depending on the part of the brain affected. Similar results may ensue from blocking of the arteries by atheroma. These conditions are illustrated by Figs. 225 and 226.

Senile Decay.—In the decade for 1891 to 1900 of persons above the age of seventy-five years, no less than 34,822 died from heart disease, and 39,662 from diseases of the blood-vessels above that age. Nor does this even cover all the mischief done by diseases of the blood-vessels, for apoplexy, paralysis, and senile decay may all be reckoned as secondary to disease of the cerebral vessels. In his most instructive book,

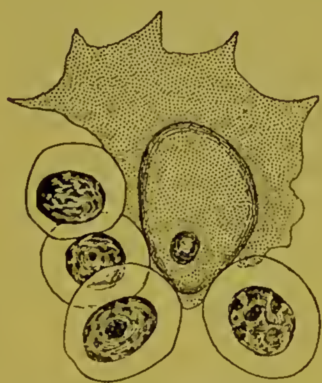


FIG. 227.—Cell from the brain of a woman, aged 100 years, being devoured by macrophags. (From Metchnikoff.)

FIG. 228.—Section of a renal tubule invaded by macrophags, from the body of an old man, aged 90 years (m = macrophags). (From Metchnikoff.)

On the Nature of Man, Metchnikoff mentions that there are two classes of phagocytes in the body, the small or microphags, and the large or macrophags. The function of the microphags is to rid us of microbes, that of the macrophags is to heal mechanical injuries, such as hæmorrhages, wounds, and so forth. In the brains of old persons and animals a number of nerve cells are surrounded and devoured by macrophags (Fig. 227), and Metchnikoff thinks himself justified in asserting that senile decay is mainly due to the destruction of the higher elements of the organism by macrophags. Other parts of the body also are not safe from their attacks, and the kidneys may likewise suffer (Fig. 228). But the function of the macrophags is not to attack healthy tissues; it is to remove those the vitality of

which is destroyed or impaired, and so long as the brain cells are abundantly supplied with blood they will probably be allowed to remain uninjured by the attacks of the macrophags. I think, therefore, that while senile decay may be actually produced by the macrophags, we are justified in believing that it really originates in an alteration of the blood-vessels.

Treatment of Senile Conditions of the Vessels.—Although I do not quite agree with him in every respect, I think that my former pupil and old friend, Dr Haig, has done a very great service by drawing general attention to the injurious effects of a too highly nitrogenous diet. In cases where the arterial tension tends to rise much above the normal, the proteids in food should be kept as low as they possibly can, consistently with the proper performance with the bodily functions. The bowels should also be kept free either by the use of salines or by small quantities of some aperient such as cascara, aloes, or rhubarb, along with each meal, so that the natural stimulating effect of food upon the bowels as well as the stomach should be increased. Nor should the occasional use of a mercurial purgative be omitted, and here I may mention that the danger of mercury in albuminuria has, I think, been greatly exaggerated, and has sometimes in my own experience been productive of much harm, for I have met practitioners who have been so imbued with the fear of mercury that they would not give it in cases of cardiac disease either as a purgative or in combination with digitalis, because albumen had appeared in the urine. Whereas in these very cases mercury was one of the best things to restore the circulation to its normal condition and cause the albumen to disappear.

The steady employment of iodides is sometimes most useful, and I have found great advantage in a number of cases of high tension from 20 grains of nitrate of potash along with $\frac{1}{2}$ to 2 grains of nitrite of sodium given in a tumbler of water or aperient water every morning on rising. This seems to keep the tension from rising too high, and the treatment may be continued with advantage for years.

Where this is insufficient, it may be supplemented by two or three grains of sodium nitrite in water every four hours, or

by nitro-erythrol in doses of $\frac{1}{2}$ to 2 grains, or $\frac{1}{100}$ grain nitro-glycerine in tablets or solution. Ammonium hippurate, as recommended by Oliver, may also be useful.

In very high tension it may be advisable to bleed from the arm. The effect of this in relieving angina was most strikingly shown in the patient whom I was afterwards able to relieve by the use of nitrite of amyl (*Clin. Soc. Rep.*, vol. iii., 1870; and, *Collected Papers*, p. 186).

By careful estimation of the blood pressure, and by keeping the tension at a proper level by diet regimen and medicines, I believe that the cardiac failure or the cerebral apoplexy, which are common causes of death in advanced years, may be averted for years, and the life not only prolonged greatly, but the senile decay or paralysis, which are so trying to the patients themselves and their friends, may be prevented.

As I mentioned in my first Lecture, the Therapeutics of the Circulation is a very large subject, and I have been able to treat it only sketchily and imperfectly, but the general outlines I have given may be a guide in further reading on the subject; whilst the prominence I have given to the subjects at which I have worked experimentally is, I believe, in accordance with the general purpose of the University in establishing such lectures.

APPENDIX A

Functions of Protoplasm.—In Lecture I. (page 22), I mentioned that protoplasm can contract independently of nerves, and that partially differentiated protoplasm might possess the functions both of muscle and nerve. It was impossible to enter more fully into this subject in the lectures; but as it is one of great interest, I have thought it worth while to deal with it in an appendix, especially as books in which it is discussed are not always of ready access, even to those who are able to consult public libraries.

Contractility and Conduction of Stimuli by Vegetable Protoplasm.—My attention was first directed to this subject by the late Professor J. Hutton Balfour, and in his class of Botany in 1865 I wrote a prize essay on the movements of plants and the action of drugs upon them. The experiments I made on the subject added little to the results already obtained by Marcet, Macaire-Prinsep, Dutrochet, Brücke, Livingston, and Coldstream, and the essay was not published. I experimented chiefly with the sensitive plant (*Mimosa pudica*). The leaves of this plant have numerous small leaflets standing out on each side of the midrib, or like the teeth of a double comb. If the swelling at the base of one be touched, the leaflets fold up together, and the irritation spreads to the neighbouring leaflets, which fold up. If the plant is in good condition, the stimulus affects the whole leaf, which falls down instead of standing out from the stem. Marcet found that chloroform at first acts as an irritant, and causes the leaflets to fall. After a while they recover, but are then insensible to touching. This condition appears to be analogous to the effect of chloroform on animals, in which it frequently produces struggling and afterwards anæsthesia. I found in my experiments that alcohol dropped on the leaves had a somewhat similar, though less marked effect. Perhaps one passage from my unpublished essay may not be without interest, and so I give it here :—" When

I began to write this essay, I had an inclination to the belief that plants as well as animals have a nervous system, but I now think that if they do possess something analogous to it, yet it is very different in kind. However, it is possible that researches on the motions in cells of plants may yet lead to some light on that mysterious part of the animal economy, and help to solve the question which so long has engaged the attention of all medical men, "How do medicines act?—for most of those are poisons, and if we could only find out how poisons act on the vegetable organism, a great step would be gained towards our knowledge of their action on animals."

Animal Protoplasm.—In the amœba (Fig. 27, page 25), and in the leucocytes of higher animals, every part of the protoplasm of which they consist appears capable of exercising the functions of receiving and conducting stimuli, of contracting, and of secreting. In low organisms, such as the hydra, differentiation occurs but incompletely, and the same is the case in the embryos of higher animals.

Neuro-muscular Cells.—It has been shown by Kleinenberg and Ranvier that in the fresh-water hydra the protoplasm in some of the cells appears to have the power of receiving stimuli

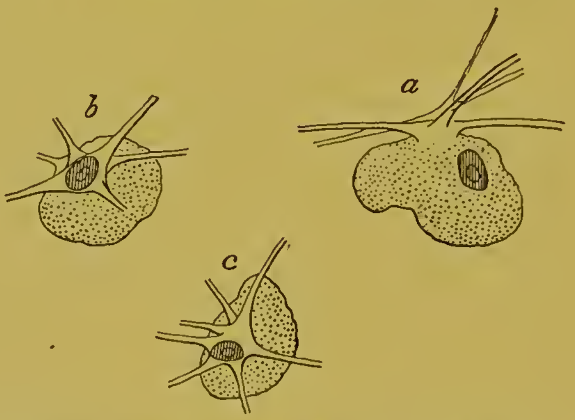


FIG. 229.—Neuro-muscular cells from the fresh-water hydra. *a*, A neuro-muscular cell seen in profile; *b*, a three-quarter view; *c*, a frontal view. (After Ranvier, *Leçons d'Anatomie Générale sur le Système Musculaire*, Paris, Delahaye & Co., 1880, p. 328.)

and also of contracting; in fact, of performing the functions of both nerve and muscle. To these cells the name of neuro-muscular has been given. Ranvier's description is so clear that I have translated it almost verbatim.[1]

The body of the hydra consists of a cylindrical tube, open at

[1] Ranvier, *Leçons d'Anatomie Générale sur le Système Musculaire*, Paris (A. Delahaye & Co.), 1880, pp. 325 *et seq.*

one end. The body-wall consists of three layers: an inner or endoderm, a middle or mesoderm, and an outer or ectoderm.

The ectoderm is composed of large cells lying adjacent to one another, and forming a protecting layer. Under this is the mesoderm of interlacing fibres. Internal to this is the endoderm, consisting of large cells arranged like epithelium.

The ectoderm sends into the mesoderm a series of processes. Each of these proceeds from the body of an ectodermal cell of which it seems to form a part. Kleinenberg, who first described them, supposes that the ectodermic cell with its mesodermic prolongation constitutes a neuro-muscular element (Fig. 229). The ectodermic cell corresponds to an ordinary nerve-cell, and is receptive, sensory, and excito-motory. The mesodermic prolongation represents a muscular, or at all events, a contractile element.

In the hydra, then, he supposes that the function of sensation is connected with stimulation of the ectodermic portion of the cell, and motion with its mesodermic or muscular portion. The three layers in the body of the hydra correspond to the three layers of the blastoderm in a vertebrate embryo. The ectoderm is analogous to the outer layer of the blastoderm, from which not only the integument which covers the exterior of the animal is developed, but also the central nervous system, which originates from that part of the layer which is separated by the involution of the primitive groove. The mesoderm of the hydra corresponds to the muscular system of vertebrates, which is developed in the middle layer of the blastoderm, and remains connected on the one hand with the nerve centres which have been separated from the external layer by involution, and on the other with that part which develops into integument.

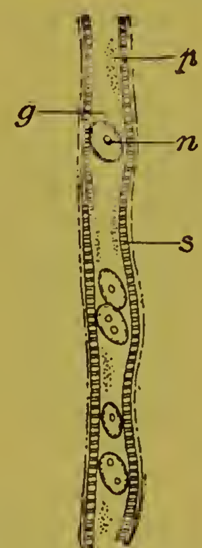


FIG. 230.—Primitive bundle from a mammalian embryo (about the third month), examined in strongly iodised serum. *n*, Nuclei surrounded by glycogenic substance *g*; *s*, striated cortex; *p*, central cylinder of protoplasm. (After Ranvier, *Leçons d'Anatomie Générale sur le Musculaire*, Paris, Delahaye & Co., 1880, p. 374.)

In the hydra the ectodermic cells have three functions, viz., (1) they protect the surface; (2) they act as sensory nerves; and (3) as excito-motor agents.

Amongst animals more completely differentiated, these different qualities, instead of being united in a single anatomical element, become associated with special elements whose forms are adapted to their functions.

The hydra when irritated contracts strongly. According to Ranvier, it is very easy to understand this, if its mesodermic cells are contractile. But it can elongate itself as well as contract, and this active elongation Ranvier says is difficult to understand, and he will not offer an explanation of it. But if

FIG. 231.—Cells of involuntary muscle from the bladder of the dog, showing traces of striation. (After Schwalbe.)

we suppose the cells to have the power of contracting transversely as well as longitudinally, *vide* page 44, the explanation is simple enough. In embryonic muscle the fibres are only striated at the side, and the anterior consists of undifferentiated protoplasm, Fig. 230.

FIG. 232.—Purkinje's fibres from a sheep's heart. *n*, Nuclei; *c*, protoplasm; *f*, striated muscular substance. (After Ranvier, *Leçons d'Anatomie Générale sur le Système Musculaire*, Paris, Delahaye & Co., 1880, p. 300.)

A slight tendency to striation has been observed by Schwalbe in the involuntary muscle of the bladder in the dog (Fig. 231).

In the cells of Purkinje a striation similar to that in embryonic muscle (Fig. 230) exists at the periphery of the cell (Fig. 232).

The function of these cells has long been a mystery, but they are now coming to be regarded as the conductions of stimuli from the auricles to the ventricles, and thus maintaining or assisting to maintain, in conjunction with nerves, the co-ordination of the auricular and ventricular pulsations (p. 34).

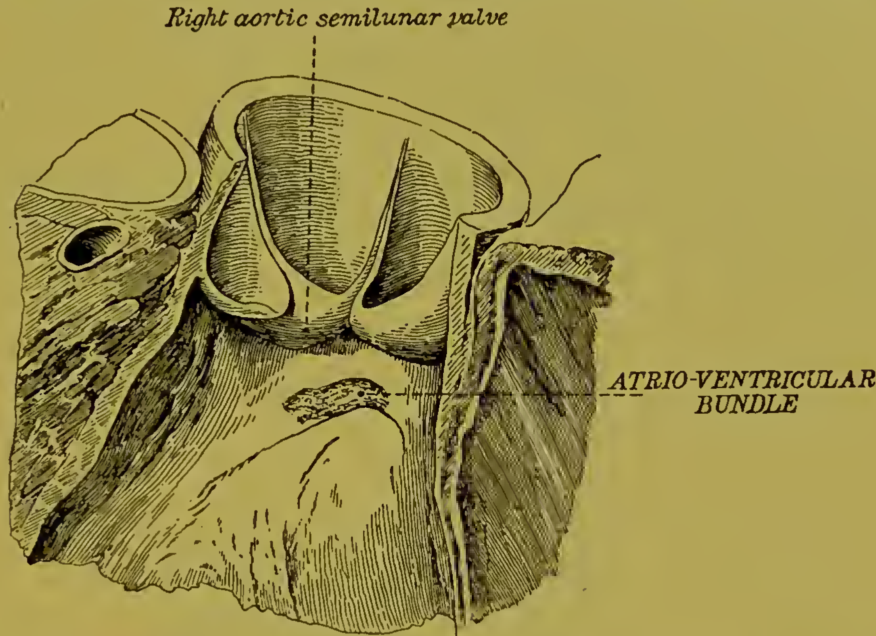


FIG. 233.—Atrio-ventricular bundle of Stanley-Kent and His, seen from the right ventricle. (From Morris's *Anatomy*, after Retzer.) For description, *vide* p. 35.

Bundle of Stanley-Kent and His.—This has been described in the lectures (page 35), but its position and relations will be more easily understood from the accompanying figure (Fig. 233).

APPENDIX B

Instruments for measuring the Blood-pressure in Man.—Janeway's has been mentioned (page 80), but may be here described.

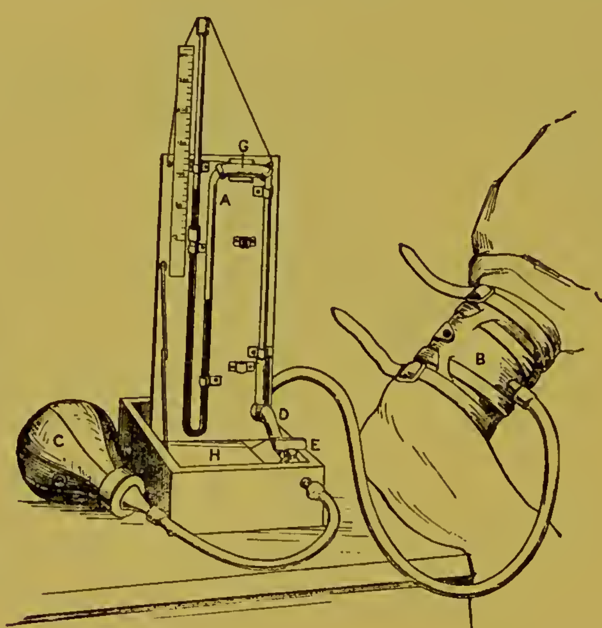


FIG. 234.—Janeway's sphygmomanometer.

It employs the method of circular compression, introduced by Riva-Rocci and Hill, with the wide armlet, proved essential by v. Recklinghausen. The jointing of the manometer tube is copied from Cook, the use of a Politzer inflator from Erlanger. The apparatus is designed to embody in a portable clinical sphygmomanometer, which shall measure both systolic and diastolic pressures, every requirement for accuracy and substantiality.

The sphygmomanometer consists of three essential parts.—A, Manometer, of U-tube form, with upper part jointed, fixed

to the under side of case lid. The scale is graduated empirically for each manometer, and is accurate. B, Compressing armlets, consisting of a hollow rubber bag 12 by 18 cm. This is attached to an outer leather cuff, which fastens by two encircling straps with friction buckles. C, Inflator, an 8-oz. Politzer bag with valve. D, Tube connecting the manometer and armlet, E, Stopcock with needle valve to allow slow release of pressure. F, A small cock to close the open end of the manometer. G, A rubber joint which is compressed by a block and closes the other end of the manometer when the box is shut. H is a spring to hold the stopcock in place when the box is shut. It is made by C. E. Dressler & Co., 143-147 East Twenty-third Street, New York. It can be obtained from Mr Hawksley, 357 Oxford Street, London.

C. J. Martin's new modification of Riva-Rocci's instrument

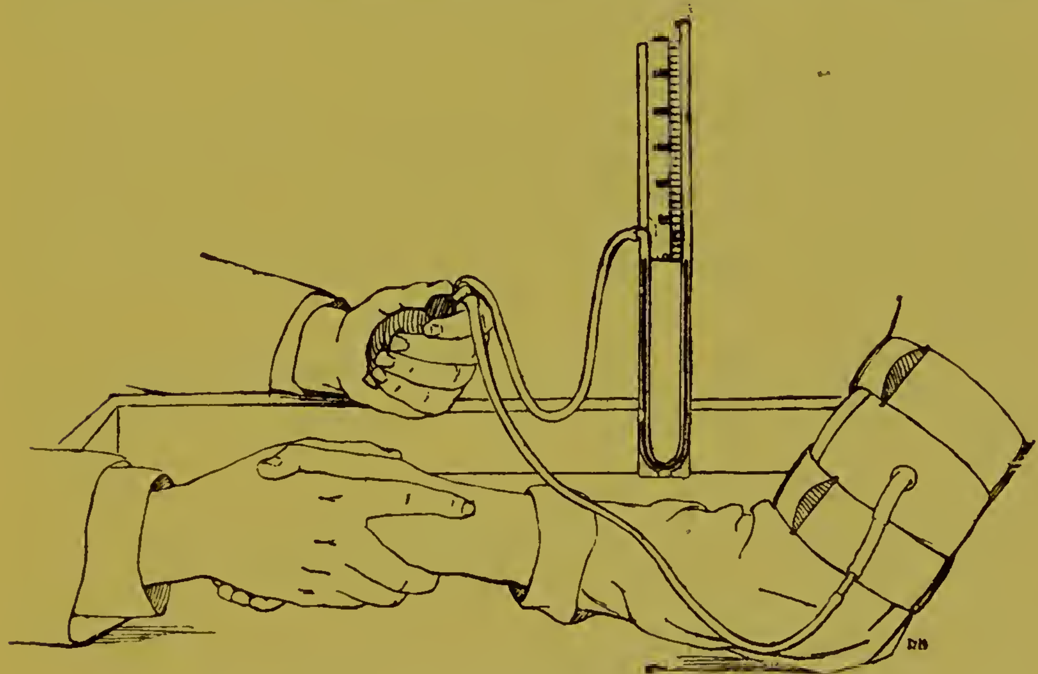


FIG. 235.—C. J. Martin's modification of Riva-Rocci's sphygmomanometer.

is one of the best of the new instruments which have been introduced since these lectures were delivered. His earlier one is described at page 76. The newer one has all the advantages of the earlier, and has the additional one of being portable. Mercurial manometers, as a rule, are troublesome, as the mercurial column is apt to break or the mercury to be spilled, but in this instrument the india-rubber caps, if well pushed home over the openings of the tubes, prevent this from occurring.

Description of Martin's improved form of Riva-Rocci's Sphygmomanometer.[1]

The apparatus consists of a bag of thin rubber, $\frac{1}{50}$th of an inch in thickness, $13\frac{1}{2}$ inches long, and 4 inches broad, the interior of which communicates with a piece of small-bore rubber tube. The rubber bag is covered on the outside by unyielding leather, and loosely on the inside with soft, thin material. This bag is wrapped round the arm over the biceps, so that the ends overlap, and secured by straps, so adjusted as to fit closely to the arm.

The interior of the bag communicates by rubber tubing on the one hand with a mercury manometer, and on the other with a rubber ball. A side tube near the ball is closed by a screw and leather washer; by loosening this, the air in the system may be allowed to escape.

The manometer is of the ordinary U-tube variety, 12 inches in length, and made of thick glass tube. It is provided with a scale, which is graduated so as to indicate the pressure, in millimetres of mercury. The glass tube is fixed to a piece of wood, which latter fits into a socket on the side of the interior of the box.

The manometer can be carried in any position, provided the ends be secured with the rubber caps. The whole apparatus is fitted into a box in such a way that there is no danger of damaging the glass tube.

One millimetre of the scale really indicates 2 millimetres of pressure, as the rise of the mercury in one limb of the manometer is accompanied by a corresponding fall in the other. This is accounted for in the marking of the scale so that the pressure can be read off directly from the numbers on it without the necessity for any calculation.

Directions for using the instrument.—Fix the manometer in the socket and remove the rubber caps. Wrap the bag evenly round the right arm of the patient, over the biceps, either next to the skin or over soft clothing, *so that the ends overlap.* (With children the bag can be placed round the thigh.) Secure the bag by means of the straps.

The arm and hand of the patient must rest upon a table at the level of the heart, and the finger of the observer's left hand

[1] C. J. Martin, *Brit. Med. Journ.*, April 22, 1905.

be kept upon the pulse. Loosen the brass screw valve near the ball, and see that the level of the mercury stands at zero on the scale. If this is not the case, adjust the tube by pushing it up or down until the mercury is at this level. Attach one end of the tubing to the manometer and the other to the glass tube connection of the bag. Screw the brass outlet-valve tightly home.

The pressure in the bag is now slowly raised by squeezing the ball with the right hand until the pulse can no longer be felt. At this point the rise of the mercury in one limb of the manometer is read on the scale, and the figure on the scale indicates the *maximum systolic pressure* at the time.

Having read off the pressure in the manometer, allow the air to escape by loosening the brass screw near the ball. By allowing the air to escape slowly, the pressure at which the pulse returns can also be observed.

The diastolic pressure is ascertained by allowing the pressure to fall still farther very slowly, and noting the height at which the greatest oscillations of the mercury occur at each pulsation.

When packing the manometer in its case, remove it from the socket and replace the small rubber caps securely and tightly on the open ends, to prevent the mercury escaping. Then put the manometer in the guides at the bottom of the box, face upward, the scale-end nearest to the handle. Upon this lay the armlet, leather side upward. The tubing, ball, etc., may be distributed about the case. Carry the box by means of the hand-loop at the end.

The scale on the manometer is immovable, but the glass tube admits of a small movement. Should any of the mercury be accidentally spilled, refill the tube, and bring the surface of the mercury to correspond with the zero on the scale. Spilled mercury may be scooped up with a bent calling card. Care must be taken not to use a silver teaspoon, which would at once become amalgamated and spoiled. Gold or silver rings or sleeve-links must also be prevented from touching the mercury, or they will be spoiled.

Note.—A fall on the floor, or the jolting in travelling by rail, may separate the two columns of mercury in the manometer tube; to rectify this, hold the manometer board by its upper end, and gently swing it in the manner adopted to adjust the index of a clinical thermometer; leave the rubber caps on the tubes whilst so doing.[1]

[1] It is made by Mr T. Hawksley, 357 Oxford Street, London, W.

Lockhart Mummery's is much like C. J. Martin's, but it has a large reservoir of mercury like Riva-Rocci's original instru-

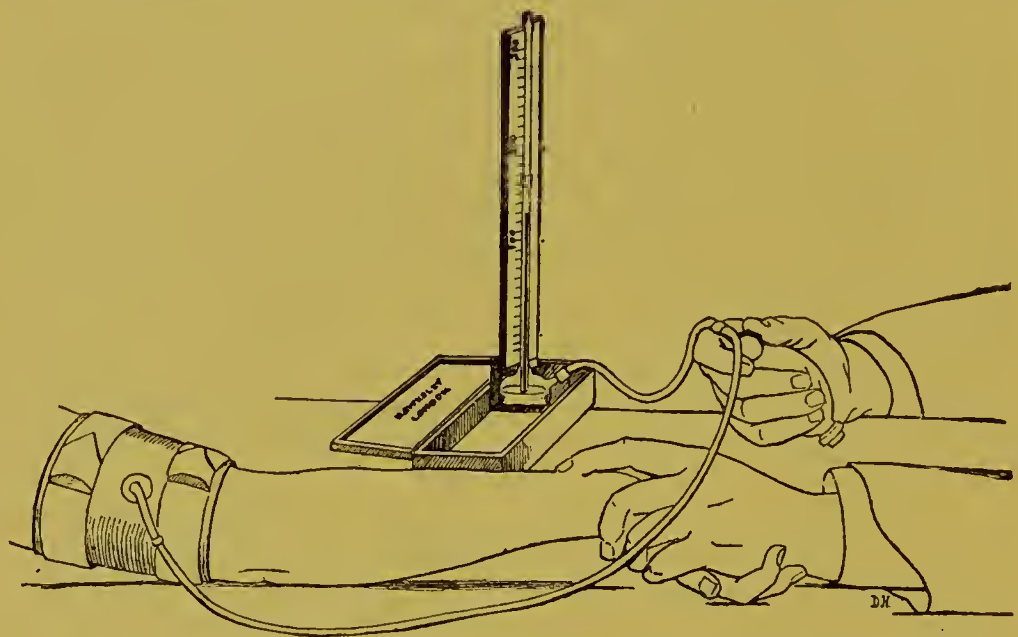


FIG. 236.—Lockhart Mummery's modification of Riva-Rocci's sphygmomanometer. (Made by Hawksley.)

ment (page 76), instead of a U-tube. The mercury is retained by india-rubber caps, and the instrument is portable.

Oliver's New Sphygmomanometer.—In this instrument the

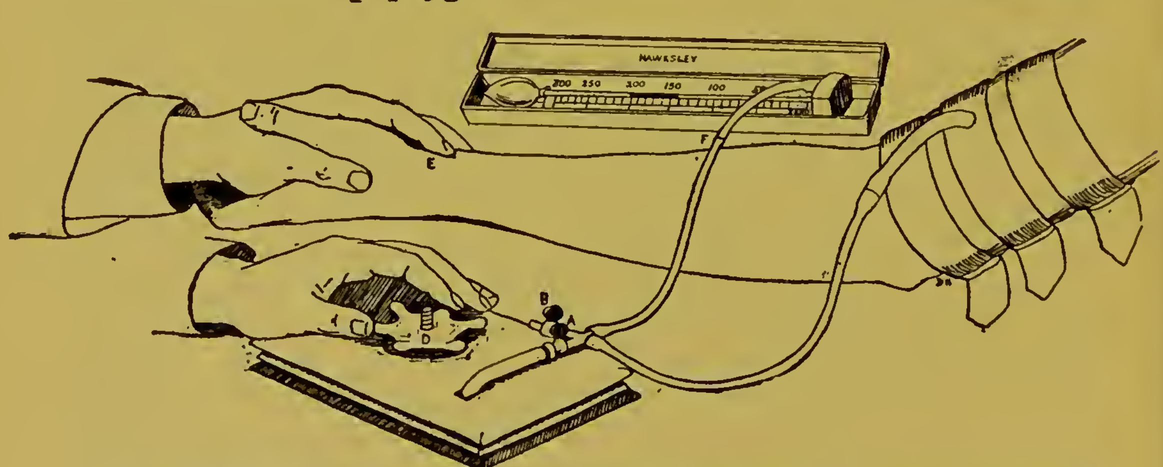


FIG. 237.—Oliver's new instrument. A, Tap for occluding or releasing air; B, tap for augmenting the oscillations of the fluid index; C, rubber connections; D, screw for regulating the pressure in the air bag; E, the palpating finger; F, sphygmomanometer.

pressure is afforded, as in Hill's smaller one (p. 66), by a fluid index working against a column of compressed air. It has the

convenience of a long scale, so that the oscillations of pressure at every beat of the pulse are very distinct, and the diastolic pressure (page 80) is more easily read than with most other instruments. This is made all the easier by raising or lowering the pressure by the action of a screw, in much the same way as in Gaertner's tonometer (Fig. 95, page 72).

Gibson's Clinical Polygraph.—This instrument is intended to give simultaneous tracings of the apex beat, and respiration, of the radial artery and jugular vein.

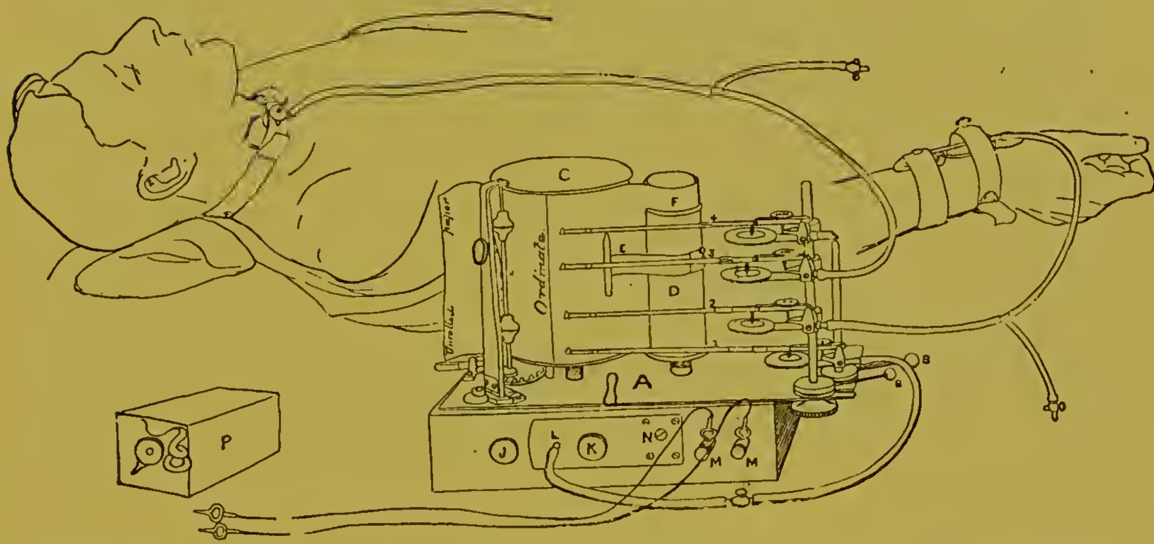


FIG. 238.—Dr A. G. Gibson's clinical polygraph. A, Rectangular box, containing driving mechanism and electric time-marker. Outside box—Driving cylinder C, cell for strip of paper D. Pillar to hold three tambours and (a second) to carry time-marking tmbour. Nos. 1, 2, 3, 4, are the writing levers of the four tambours. Each tambour capable of vertical adjustment on its pillar, and an angular adjustment by the screws . .. . B B Are levers for throwing the pens out of action when filling with ink or changing the paper. C, Driving cylinder. D, Cell to hold paper. E, The adjustable spring, keeps the paper flat against the driving cylinder when at work. F Is the unwound coil of paper in its cell. H, An axle carrying two friction rollers, adjusted for pressure by the screw at side. J, Screw to be removed when the time-marker is to be used. It screws into the "bob" of the pendulum, inside the box, and keeps it in safety when travelling, etc. K, By screwing in, lifts the receiver away from the pendulum and diminishes the force of impact. L Is the air tube of the receiver inside the box, which is struck by the pendulum "bob" five times per second. This tube communicates with the writing tambour as shown. The stopcock governs the amount of air passing to the tambour. M M Are terminals for the single cell to drive the time-marker. N Is an adjusting screw for the time-marker, which, when listened to, should coincide with the ticking sounds of a watch held to the ear. The latter are five to the second. P is an ordinary dry cell. Receivers for the jugular pulse and radial artery are shown *in situ*. Side tubes and stopcocks are for regulating the air contents of the receivers ; *i.e.*, a little more or less air may be wanted in the receivers, and it is easily blown in by the mouth, or let out by the tap. Both Oliver's and Gibson's instruments are made by Hawkesley.

A number of other instruments might very well have been described here, but I have no illustrations of them, and without illustrations a letterpress description is hard to understand. All those instruments mentioned in the lectures, of which the illustration bears the name of Ch. Verdin, can be obtained from his successor, M. Boulitte, 7 Rue Linné, Paris.

Choice of Instruments for Measuring Blood Pressure.—For any one who has only a single instrument, my experience leads me to think that Martin's new form of Riva-Rocci is at once the cheapest and the best. If he has more than one, it is very convenient indeed to use one of Von Basch's or Potain's, as it is so easily applied. If any doubt arises, Martin's instrument, which is, I think, more accurate, can be used to control the figure by Von Basch's or Potain's. The accuracy of either of these can be tested with the mercurial manometer, as shown at page 81, but if Von Basch's instrument is employed as supplied by Down Bros., a three-way stopcock must be got also, either from them or from Boulitte or from some other maker.

APPENDIX C

Exercise in Angina Pectoris.—This question came on at a late period in the lectures, when I had to deal with it very briefly, but I discussed it rather fully in my Harveian Oration, from which I may take the following quotation:—"The circulation through the muscles is indeed a complex phenomenon, and it was shown by Ludwig and Sadler to depend at least upon two factors having an antagonistic action. When a muscle is thrown into action, it mechanically compresses the blood vessels within it, and thus tends to lessen the circulation through it, but at the same time the stimulus which is sent down through the motor nerve, and which calls it into action, brings about a dilatation of the vascular walls, and thus increases the circulation throughout the muscle.

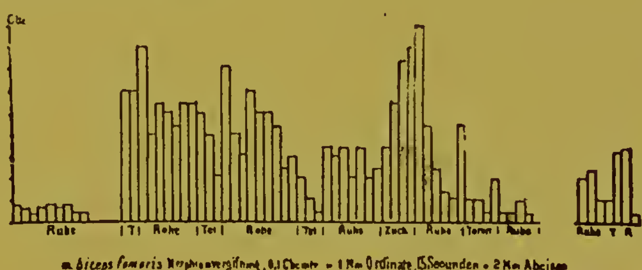


FIG. 239. After Ludwig and Sadler. The marks along the base-lines indicate seconds; the height above the base-line indicates the amount of blood flowing from the veins of the biceps of a dog during tetanus (T or tet), during rest (Ruhe), or during simple contraction (Zuck).

When the amount of blood is measured before, during, and after stimulation of the motor nerve, it is sometimes found that the flow is diminished, at others that it is increased. This difference depends upon the comparative effect of the mechanical compression of the vessels of the muscles just mentioned, and upon the increase of their lumen by the dilatation of their walls. It invariably happens, however, that after the muscle has ceased to act, the flow of blood through the muscle is increased. This increase is quite independent of any alteration in the general pressure of blood in the arteries, and it occurs when an artificial

stream of blood, under constant pressure, is sent through the muscle. A heart whose nutrition has been weakened by disease of its arteries, and consequent imperfect supply of blood to the cardiac muscle, is unable to meet any increased resistance, if this should be offered to it, and pain is at once felt. In such cases, unless they be far advanced, we find, precisely as we might expect, that walking on the level usually causes no pain, but the attempt to ascend even a slight rise, by which the muscles are brought into more active exertion, brings on pain at once. Yet here again we find, as we should expect, that if the patient is able to continue walking, the pain passes off and does not return. These phenomena would be inexplicable if it were not for Ludwig's observations on circulation through the muscles; but in the light of these observations, everything is made perfectly intelligible. Walking on the flat, by causing no violent exertion of the muscles, produces no mechanical constriction of the vessels, and thus does not increase the blood pressure. The greater exertion of walking up a hill has this effect; but if the patient is able to continue his exertions, the increased dilatation of the vessels—a consequence of muscular activity—allows the pressure again to fall, and relieves the pain.

APPENDIX D

NOTES BY PROFESSOR KRONECKER.

This appendix contains a number of notes which Professor Kronecker has kindly sent me relating to his own work and that of his pupils on the heart. His notes are especially valuable, because they afford such clear evidence of the conduction of stimuli in the heart by nervous channels, which it is at present rather the fashion to neglect. Conduction of stimuli is by many regarded as a function of muscle only, just as their conduction was regarded as a function only of nerves several years ago. The truth probably lies between the two extreme views, and conduction occurs through both channels as mentioned at p. 32. The question is by no means one of mere scientific interest, because on its correct answer a correct knowledge of the causation and treatment of heart-block depends. I have not been able to use the whole of the material with which he kindly furnished me, for it arrived just as this book was going to press, and to obtain the illustrations required would have entailed considerable delay.

His observations on self-massage of the heart and arteries are also most interesting, for though Brücke (p. 94) indicated the suction action of the cardiac systole, and Ludwig showed the effect of muscular action on the flow of lymph (pp. 8 and 9), yet it is to Kronecker that we owe the first full discussion of the self-massage of the heart and arteries.

The Work of the Heart.—The heart does not beat at the expense of its own tissues, but only at that of the energy-supplying material with which it is fed. The smaller the quantity of this material, the less is the work done by the heart. No other material enables the heart to beat except serumalbumin, and, to a very slight degree, serumglobulin. Only very minute quantities of this are required, on account of the high energy-value of the albumen. Neither glycogen

nor other carbohydrates can supply the place of genuine albumen. Of course, inorganic solutions do not supply energy. Solutions of inorganic salts, as mentioned by Gaule, Binger, Howell, Locke, Schucking, and others, weaken the pulsations; but the better they enable the albuminates to be utilised in the heart, the less do they have this effect. Every saline solution gradually exhausts the energy of the heart, but it can be restored by serum. The blood corpuscles and fibrin do not take part in this process, and hence blood is no better than serum as a nutrient.

Oxygen does not increase the work done by the heart. Blood saturated with carbonic oxide nourishes it just as well as arterial blood. Asphyxial blood is only poisonous on account of the CO_2 it contains.

Dissolved erythrocytes (laky blood) poison the heart only on account of the poisonous potassium salts set free by their solution. If these are renewed by dialysis, laky blood is innocuous.

In 1874 Kronecker advanced the following explanation of the ascending staircase (Bowditch's Treppe, p. 26):—The pulsating heart massages itself. In amphibian hearts, where capillary clefts replace the coronary arteries, each systole presses out the contents of the clefts, each diastole allows the clefts to reopen. By this mechanism the nutritive material is renewed. After a long standstill the products of metabolism remain in the clefts and asphyxiate the heart muscle. Every systole removes a small quantity of the noxious substances, and their place is supplied by nutrient material. In this way we have the paradox of recovery through work. The descending stair can be artificially produced by washing out the heart with saline solution.

Bowditch's Law.—The amplitude of the heart's beats is absolutely independent of the irritability of the heart. The law discovered by Bowditch is: *Minimal stimuli cause maximum pulsations.* This law has been thus paraphrased: "All or nothing"—that is to say, that instead of a weak stimulus evoking a weak contraction, and a strong stimulus a strong contraction, any stimulus which will produce a contraction at all will produce as powerful a pulsation as the most powerful stimulus.

To this law Bowditch found two exceptions:—

(1) Intermittent pulsation, with constant regular normal stimulation.

(2) Feebler pulsations after longer rest.

This subject was more fully investigated by Kronecker, who

succeeded in obtaining a pulsation without fail on the application of each minimal stimulus, if the stimuli were kept of exactly equal strength by the use of a mercurial contact kept perfectly clean by a constant stream of water.

He also showed that the first pulsations after rest were not smaller than the later, if the contents of the heart were kept fresh during rest.

Thus he proved that Bowditch's law holds good without any exception.

Refractory Period.—More important still was Kronecker's discovery that the heart is not irritable during systole. Marey called this the refractory period (p. 31). Even after the systole is over, the heart only gradually regains its irritability. Temperature modifies the irritability of the heart to a great extent. He found that at a temperature of 30° C., a heart can be made to beat sixty times a minute by induction currents of 15 units (Kronecker) and the contracture augments. When cooled to 8° C., it can beat twelve times per minute; at 5° C., only six times per minute, even when 12 stimuli of 30 units each are applied. Every pulsation lasts about 5 seconds, so that the new systole begins after 5 seconds of diastole.

This curious reaction of the heart to frequent (intermitting) stimuli explains why the heart cannot be tetanised.

The frog's heart, at a temperature of 30° C., and stimulated forty to fifty times per minute, makes a pulsation every second. At a medium temperature, 15° C., it pulsates about every second second. At a low temperature, 10° C., it beats about every fifth second, although the pulsation only lasts 2·5 seconds. In the cold heart the duration of the pulse is 6 seconds, but the heart only regains its irritability again after 15 seconds. This behaviour of the frog's heart supplies an explanation of the fact that constant stimuli, such as chemical ones, have an intermitting effect. Within the last few years, Kronecker and his pupils have found that the ventricle of the frog's heart ceases to beat if its contents are deprived of all stimulating properties. Thus, Algina found that a ventricle would remain without beating for an hour and a half at a time for as long as three days, when it was supplied with sheep's serum which had been dialysed, neutralised, and then brought up to 0·6 per cent. of sodium chloride content.

It would therefore seem that there is no true automatism in the ventricle, but only intermittent action to a constant stimulus.

Co-ordination of the Heart-Beats.—Two opposite views are held by physiologists in regard to this subject.

Those who hold the myogenic view consider that the muscular cells which form the cardiac wall transmit a stimulus from one to another. But Kronecker and Imchanitzky * made the following observation, which seems to show that this is not the case. Microscopic preparations of rabbits' hearts fixed in a state of fibrillation show that the condition of irritation does not pass the limits of the cell. Preparations of hearts, which were fixed while the pulsations were normally co-ordinated, exhibit equidistant striæ. Co-ordination is effected by numerous plexuses of non-medullated nerves. As soon as these are paralysed, the heart falls into an irregular kind of motion, either fibrillary or peristaltic.

The nerve centres of the heart, like those of the brain, consist of groups of ganglion cells and nerve plexuses. These are quickly paralysed by want of blood.

Fibrillation occurs in the mammalian heart—

1. If the coronary arteries are ligatured.
2. If small branches of the coronary arteries are plugged by embolism (reflex effect).
3. If the heart is tetanised.
4. If the mammalian heart is quickly cooled down to about 25° C.
5. If the ventricular septum is punctured about the junction of the upper and middle third.
6. Sometimes by the rapid application of chloroform.

Rabbits' hearts in a state of fibrillation may spontaneously commence to beat rhythmically. Dogs' hearts (except when the animals are very young) continue to fibrillate, and die unless they are saved artificially. Dogs' hearts may be saved from a state of fibrillation—

(1) By very strong electric shocks (240 volts), applied directly to the heart (Batelli and Prevost).
(2) By heating to 43° C. or 45° C.
(3) By chloral-hydrate (Barbèra).

If the roots of the coronary arteries have been ligatured, they cannot be saved.

Kronecker succeeded in re-establishing pulsation, but only on the right ventricle of the dog's heart, in the following experi-

* *Archiv. Internation. de Physiol.*, vol. iv., p. 1, July 1906. This paper contains a very complete *résumé* of the literature on the subject of the channels through which stimuli pass from one part of the heart to another.

ment. He ligatured the anterior root of the coronary artery; then produced fibrillation, and finally conducted a strong current of 240 volts through the heart. From this he concluded (1) that narrowing of the coronary arterial system paralyses, either directly or reflexly, the co-ordinating nervous system of the heart; (2) that the paralysis may be removed by producing dilatation of the coronary arteries by heat, chloral-hydrate, or electric currents of high intensity; (3) that a centre for the innervation of the coronary vessels lies in the ventricular septum. At the point in the ventricular septum where puncture produces fibrillation, no ganglion cells are to be found, but only nerve plexuses, which have a similar function to ganglia.

Conduction of Stimuli from Auricles to Ventricles.—When the heart is beating normally the two auricles are seen to contract simultaneously, and the same is the case with the ventricles. The co-ordination between the auricles and ventricles is such that they begin their contraction at regular intervals, so that the completion of systole in an auricle is followed *without any interval* by the commencement of the systole of the ventricle.

Such co-ordination is, like the act of swallowing, only possible through central nervous arrangements.

Those who hold the myogenic theory say that the retarded conduction occurs on account of the specific structure of the muscle. This is not to be found in the frog's heart. In the mammalian heart the retarded conduction is ascribed to the bundle of Stanley-Kent and His.

Kronecker and Imchanitzky have shown that this bundle can be ligatured without disturbing the co-ordination between auricles and ventricles.

Dr Paukul of Dorpat, while working recently in Professor Kronecker's laboratory, found that the Stanley-Kent and His bundle of muscular fibres connecting the auricles and ventricle is accompanied by nervous plexuses, injury of which disturbs co-ordination, whilst ligature of the muscular part of the bundle does not impair co-ordination.

Dr Imchanitzky, also working under Kronecker's direction, discovered in the hearts of lizards two nerves with immense groups of ganglia uniting the auricle with the ventricle. When these were ligatured, the co-ordination between the beats of the auricle and ventricle was destroyed.

Dr Lomakina several years ago observed disturbance of co-ordination, after the application of ligatures to the hearts of dogs and rabbits at points where the bundle could not be

injured—*e.g.*, to the pulmonary artery at its exit from the right ventricle.

Kronecker often saw inco-ordination occur on the application of a ligature to the right ventricle at the point where the venæ-cavæ inosculate. How is it possible on the myogenic theory to explain the occurrence of fibrillation in the tetanised auricles while the ventricles are pulsating normally, or *vice versa?* Is His's bundle then in a state of fibrillation and yet effecting pulsations?

Kronecker also showed that the vagi when stimulated can inhibit the ventricles whilst they do not affect the fibrillating auricles. How can this fact be explained otherwise than on the hypothesis that the nerves conduct the inhibition through the fibrillating muscular masses?

The cardiac vagi do not act on cavities of the heart which are under the influence of local stimulation. A ventricle through which normal saline solution is being circulated cannot be stopped by stimulation of the vagus, but if the ventricle is supplied with Ringer's solution or blood, stimulation of the vagus produces its ordinary inhibitory effect. The same minimal stimulus which will cause the ventricle in a state of ordinary rest to pulsate, suffices to produce a pulsation in an inhibited ventricle. The vagus is therefore not an anabolic nerve.

Conduction of Stimuli in the Heart.—In a paper on this subject from Kronecker's laboratory, Dr Maria Imchanitzky (*Archives Internationales de Physiologie*, vol. iv., p. 1, July 1906) in addition to a very full abstract of all the literature on the subject, gives a *résume* of the results of original experiments made under Kronecker's direction. These are:—

I. From the histological researches it appears:—

(*a*) That the muscular cells in the ventricles of the heart in repose, or in co-ordinated action, present everywhere the same histological appearance, the striation being identical everywhere.

(*b*) When the heart is fixed in a state of fibrillation, the cells, on the contrary, present different aspects. The state of striation differs from one cell to another. The intercellular limits generally form sharply marked dividing lines between a cell with striæ widely apart and another with them close together, although sometimes these different appearances can be found in one and the same cell. (See Fig. 240.)

(*c*) From the aspect of these structures one must conclude that the contraction does not pass from one muscular cell to

another, but that the stimulation is transmitted by co-ordinating nervous communications.

II. Experiments made by ligaturing the bundle of His prove that hearts may exhibit co-ordinated pulsations of the auricles and ventricles after the destruction of this bundle.

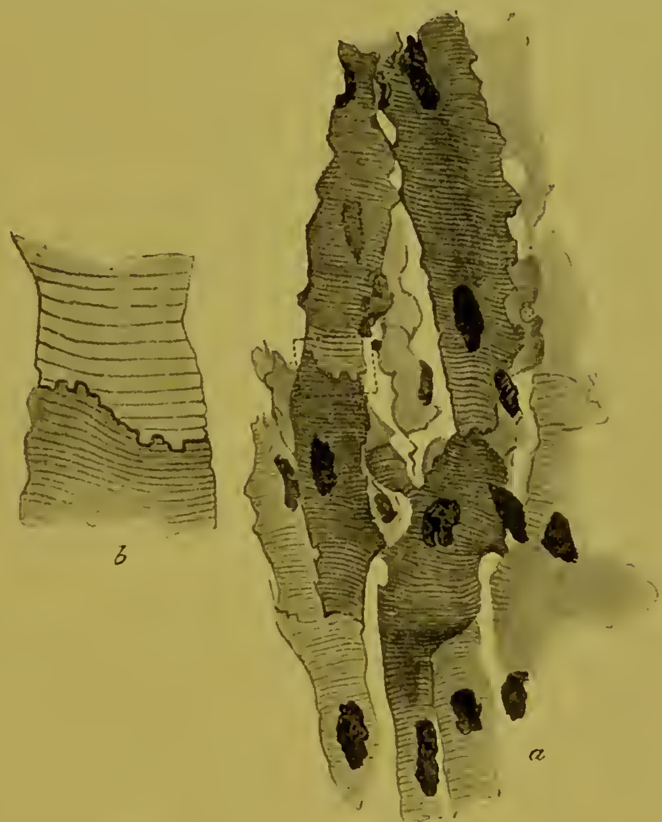


FIG. 240.—Cells taken from a heart in fibrillation. The preparation shows that the intercellular limits separate very sharply parts with striæ widely apart from others with striæ close together, whilst in the interior of the cells numerous transitions may be observed. The larger figure (*a*) is magnified 750 diameters by an apochromatic objective, No. 2 of Zeiss, and compensating eyepiece, No. 6. The small portion (*b*) strongly magnified was observed with Zeiss's No. 2 objective and a compensating eyepiece, No. 18, with an intense illumination. Its position in *a* is marked by the rectangle of dotted lines.

Importance of the Pulse for the Current of Blood in the Arteries.—In experiments made with his pupil, Dr Gustav Hamel,* in which nutrient fluid was perfused through the blood vessels of a frog, Kronecker found that when the flow was interrupted rhythmically by a stopcock worked by an electric pendulum, the vessels allowed much more fluid to flow through them than when the flow was continuous. The advantage of the rhythmical impulse appears to consist in this: that the alternate movements maintain the elasticity of the arteries and

* *Zeitschrift f. Biologie*, Bd. xxv., N.F. vii., p. 474.

the pauses serve for recuperation of their muscular walls. The intermitting rest is certainly of great value to the vascular walls, for when they are subjected to continuous pressure they are injured and allow fluid to exude into the tissues and produce œdema. On the other hand, when the flow is rhythmically interrupted, very little œdema appears (*cf.* p. 126). The cardiac pulsation acts like an internal massage, and by producing passive gymnastics maintains the cohesion, elasticity, and contractility of the arteries.

Circulation in the Splanchnic System.—In 1889 Kronecker showed at the Naturforscherversammlung, in Heidelberg, that normal saline solution flows readily into the portal venous system of a rabbit under a pressure equivalent to 30 centimetres of water. When the portal vein is ligatured close to the hilus of the liver, the saline solution only begins to enter under a pressure of 60 centimetres. But if the abdominal aorta is ligatured close to the diaphragm, and above the abdominal arteries, the veins become paralysed, and allow enormous quantities of saline solution to flow into them under a very low pressure.

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